

## Executive Summary

(NASA-TM-108089) FAST TECHNOLOGY  
FOR THE FUTURE. EXECUTIVE SUMMARY.  
NASA IN-SPACE TECHNOLOGY  
EXPERIMENTS WORKSHOP (NASA) 183 p

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IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP



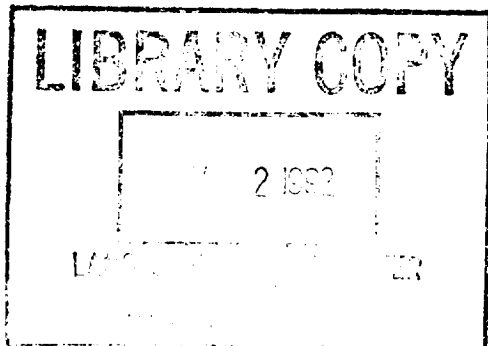
## IN-STEP 88 WORKSHOP

### FOREWORD

At the workshop, Dr. Harrison H. Schmitt emphasized that the nations which effectively exploit the advantages of space will lead human activities on earth. The major space goal of the National Aeronautics and Space Administration's Office of Aeronautics and Space Technology (OAST) is to provide enabling technologies, validated at a level suitable for user-readiness, for future space missions in order to ensure continued U.S. Leadership in space. An important element in accomplishing this goal is the In-Space Technology Experiments Program whose purpose is to explore and validate in space advanced technologies that will improve the effectiveness and efficiency of current and future space systems. OAST has worked closely with the aerospace community over the last few years to utilize the Space Shuttle, expendable launch vehicles, and, in the future, the Space Station Freedom for experimentation in space in the same way that we utilize wind tunnels to develop aeronautical technologies. This close cooperation with the user community is an important, integral part of the evolution of the In-Space Technology Experiments Program which was originated to provide access to space for technology research and experimentation for the entire U.S. aerospace community.

On December 6 through 9, 1988, almost 400 researchers, technologists, and managers from U.S. companies, universities, and the government participated in the OAST IN-STEP 88 Workshop. The participants reviewed the current in-space technology flight experiments, identified and prioritized the technologies that are critical for future national space programs and that require verification or validation in space, and provided constructive feedback on the future plans for the In-Space Technology Experiments Program. The attendees actively participated in the identification and prioritization of future critical space technologies in eight major discipline theme areas. These critical space technologies will help focus future solicitations for in-space flight experiments. The material within these four volumes is the culmination of the workshop participants' efforts to review the planning for the future of this program.

Dr. Leonard Harris  
Chief Engineer  
Office of Aeronautics and  
Space Technology, NASA





**OAST IN-STEP 88 WORKSHOP**  
**Executive Summary**

**ORIGINAL CONTENT  
COLOR ILLUSTRATIONS**

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## INTRODUCTION

NASA's Office of Aeronautics and Space Technology (OAST) conducted a workshop on the In-Space Technology Experiments Program (IN-STEP) December 6-9, 1988, in Atlanta, Georgia. The purpose of this workshop was to identify and prioritize space technologies which are critical for future national space programs and which require validation in the space environment. A secondary objective was to review the current NASA (In-Reach) and Industry/University (Out-Reach) experiments. Finally, the aerospace community was requested to review and comment on the proposed plans for the continuation of the In-Space Technology Experiments Program. In particular, the review included the proposed process for focusing the next experiment selection on specific, critical technologies and the process for implementing the hardware development and integration on the Space Shuttle vehicle. The product of the workshop was a prioritized listing of the critical space technology needs in each of eight technology disciplines. These listings were the cumulative recommendations of nearly 400 participants, which included researchers, technologists, and managers from aerospace industries, universities, and government organizations.

The identification and prioritization of the critical space technology needs were initiated by assigning NASA chairpersons (theme leaders) to the eight major technology disciplines or themes requiring consideration. These themes were as follows:

- space structures
- space environmental effects
- power systems and thermal management
- fluid management and propulsion systems
- automation and robotics
- sensors and information systems
- in-space systems
- humans in space

In order to provide further structure within each theme, the chairpersons divided their themes into three theme elements each. The theme element concept allowed focused technical discussions to occur within the broad discipline themes. For each theme element, the theme leader selected government, industry, and university experts to present the critical space technology needs of their respective organizations. The presentations were reviewed and discussed by the theme audiences (other members of the aerospace community), and prioritized lists of the critical technologies which require verification and validation in space were established for each theme element. The comments and conclusions for each theme were incorporated into a summary listing of the critical space technology needs and associated

flight experiments representing the combined inputs of the speakers, the audience, and the theme leader. The lists prepared at the Workshop were later supplemented by summaries of critical technology needs prepared in a uniform format by the theme leaders. The critical space technology needs and associated space flight experiments identified by the participants provide an important part of the strategic planning process for space technology development and provide the basis for the next solicitation for space technology flight experiments. The results of the workshop will be presented to the IN-STEP Selection Advisory Committee in early 1989. This committee will review the critical technology needs, the funding available for the program, and the space flight opportunities available to determine the specific technologies for which space flight experiments will be requested in the next solicitation.

These proceedings are organized into an Executive Summary and three volumes: In-Reach/Out-Reach Experiments and Experiment Integration Process (Volume I); and Critical Technology Presentations (Volumes II and III)

The Executive Summary contains the Welcome and Workshop Instructions, Strategic Planning for the In-Space Technology Experiments, an overview of the space technology experiments being conducted in OAST and the solicitation process for IN-STEP, the proposed accommodation process for Space Station Freedom, the Keynote Address reproduced from the workshop banquet, and the critical technology needs summaries for each theme. The Welcome and Workshop Instructions describes the purpose, the process, and the product intended for the workshop. The Space Strategic Planning process describes the OAST space Research and Technology base programs which generate new technology concepts in the major discipline areas, the new focused programs of the Civil Space Technology Initiative (CSTI) and the Pathfinder, and the new fiscal year 1990 initiative of In-Space Technology Experiments Program (IN-STEP) which provides funding for the industry, university, and NASA space technology experiments. Overview charts of current OAST sponsored space flight experiments and specific information regarding the IN-STEP solicitation process are provided to establish an understanding of space technologies currently being validated and the proposed approach for initiating new experiments. An overview of the user/payload integration and accommodation process being established for use on the Space Station Freedom is documented to promote better understanding with the space experiment community. The keynote address was presented by Dr. Harrison H. Schmitt, a former U.S. Senator and Apollo astronaut on the 16th anniversary of his lunar launch. In his presentation, Dr. Schmitt outlined his vision for the future of the U.S. space program by describing a Millennium Project which would combine space ventures to the earth, moon, and Mars. The critical technology needs summaries for each theme are as described above, standardized format versions of the lists prepared "real-time" at the Workshop. In the appendices of this Summary are the final workshop agenda and a list of workshop attendees.



## OPENING PRESENTATIONS

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# WELCOME AND WORKSHOP INSTRUCTIONS

DR LEONARD HARRIS

CHIEF ENGINEER

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY

# IN-STEP 88

~~OAST~~ ~~IN-STEP 88~~ ~~WORKSHOP~~

- PURPOSE

- IDENTIFY & PRIORITIZE IN-SPACE TECHNOLOGIES WHICH:
  - ARE CRITICAL FOR FUTURE NATIONAL SPACE PROGRAMS
  - REQUIRE DEVELOPMENT & IN-SPACE VALIDATION
- REVIEW CURRENT NASA (IN-REACH) & INDUSTRY/UNIVERSITY (OUT-REACH) EXPERIMENTS WITH THE AEROSPACE COMMUNITY
- OBTAIN AEROSPACE COMMUNITY COMMENTS & SUGGESTIONS ON OAST IN-STEP PLANS

- PRODUCT

- AEROSPACE COMMUNITY RECOMMENDED PRIORITY LISTING OF CRITICAL SPACE TECHNOLOGY NEEDS & ASSOCIATED SPACE FLIGHT EXPERIMENTS

# TECHNOLOGY THEMES

~~OASIS~~

~~IN-STEP 88 WORKSHOP~~

## IN-STEP 85 WORKSHOP

SPACE STRUCTURES

SPACE ENVIRONMENT  
EFFECTS

ENERGY SYSTEMS &  
THERMAL MANAGEMENT

FLUID MANAGEMENT

AUTOMATION  
& ROBOTICS

INFORMATION SYSTEMS

IN-SPACE OPERATIONS

## IN-STEP 88 WORKSHOP

SPACE STRUCTURES

SPACE ENVIRONMENT  
EFFECTS

POWER SYSTEMS  
& THERMAL MGMT.

FLUID MANAGEMENT &  
PROPULSION SYSTEMS

AUTOMATION  
& ROBOTICS

SENSORS &  
INFORMATION SYSTEMS

IN-SPACE SYSTEMS

HUMANS-IN-SPACE

# RESULTS OF THE WORKSHOP

~~0A-ST~~ ~~IN-STEP-83~~ ~~WORKSHOP~~

- STRENGTHEN COMMUNICATION WITH THE  
AEROSPACE COMMUNITY ON THE IN-SPACE  
TECHNOLOGY EXPERIMENTS PROGRAM
- IDENTIFY CRITICAL IN-SPACE TECHNOLOGY  
NEEDS FOR FUTURE RESEARCH & DEVELOPMENT
- PRIORITIZE SPACE TECHNOLOGY NEEDS &  
ASSOCIATION IN-SPACE TECHNOLOGY  
EXPERIMENTS

# WORKSHOP AGENDA

~~04-97~~

~~IN-STEP 88 WORKSHOP~~

- |  |   |   |
|--|---|---|
| Dec 6<br>(Tuesday Morning)                 | — | PROGRAM OVERVIEW                                      |
| Dec 6<br>(Tuesday Afternoon)               | — | REVIEW OF CURRENT IN-REACH<br>& OUT-REACH EXPERIMENTS |
| Dec 7<br>(Wednesday &<br>Thursday Morning) | — | THEME REVIEWS & DISCUSSIONS                           |
| Dec 8<br>(Thursday Afternoon)              | — | EXPERIMENT INTEGRATION PROCESS                        |
| Dec 9<br>(Friday Morning)                  | — | CRITICAL TECHNOLOGY REQUIREMENTS                      |

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**Office of  
Aeronautics and  
Space  
Technology**

**IN-SPACE TECHNOLOGY EXPERIMENTS  
IN NASA'S STRATEGIC PLANNING**

**Presentation to**

**THE IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP**

**Dr. Judith H. Ambrus  
Assistant Director  
for Space  
December 6, 1988**

(presented by Dr. Leonard Harris)

## SPACE R&T PROGRAM

### GOAL

- RECOGNIZED LEADERSHIP IN SPACE R&T TO ENABLE AND ENHANCE FUTURE CIVIL SPACE MISSIONS
- AND
- PROVIDE A SOILID BASE OF CAPABILITIES AND TALENT TO SERVE ALL NATIONAL SPACE SECTORS

# STRATEGY

~~OST~~ ~~IN-SHEP-88~~

- ENSURE INNOVATIVE R&T BASE

## LONG RANGE PLAN

- PURSUE NEW DIRECTIONS THROUGH ROLLOVER
- NURTURE NEW FOCUSED PROGRAMS
  - ULTRA-RELIABLE SYSTEMS
  - TECHNOLOGIES FOR MISSION TO PLANT EARTH
- ADVOCATE BUDGET GROWTH

## **R&T BASE CHARACTERISTICS**

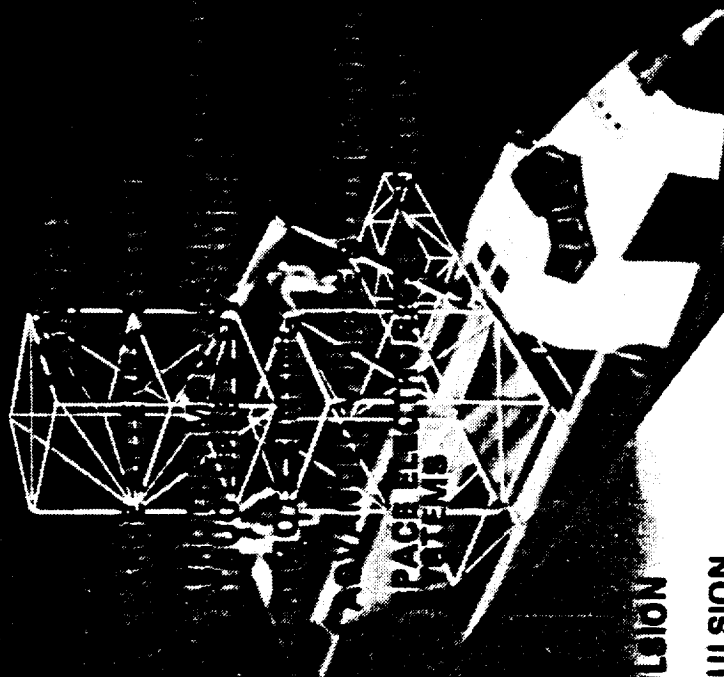
**~~OAS-T~~** **~~IN-SHEP-88~~**

- **LABORATORY RESEARCH**
- **GENERIC, FUNDAMENTAL**
- **ANALYTICAL MODELING**
- **ENGINEERING DATA BASE**
- **HIGH RISK, HIGH PAYOFF**
- **TECHNOLOGY OPPORTUNITIES**

# RESEARCH CENTERS

## AMES

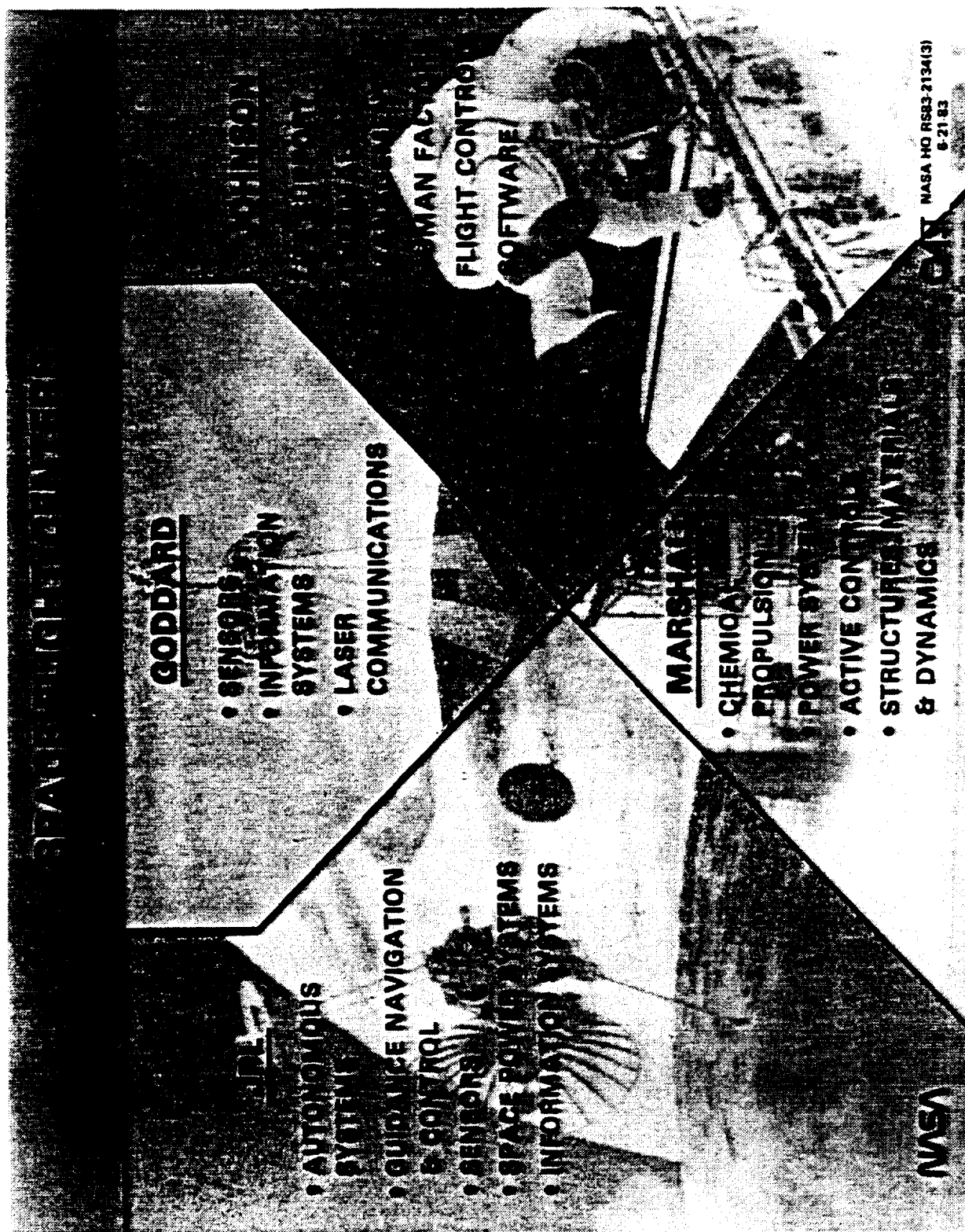
- ENTRY AEROTHERMODYNAMICS & TPS
- LIFE SCIENCES
- COMPUTED SCIENCE
- IR DETECTION



## PAGE ELECTRONIC SYSTEMS

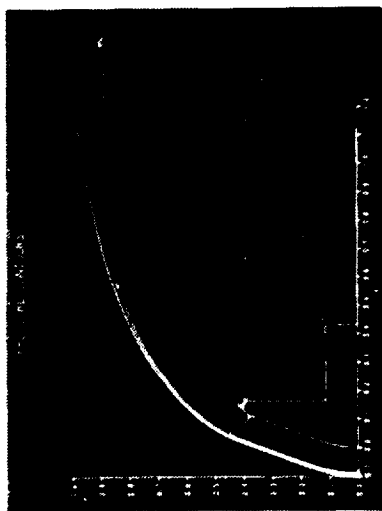
- ELECTRIC PROPULSION
- CHEMICAL PROPULSION
- COMMUNICATIONS SYSTEMS
- SPACE POWER SYSTEMS

RS87-155(3)



# AEROTHERMODYNAMICS

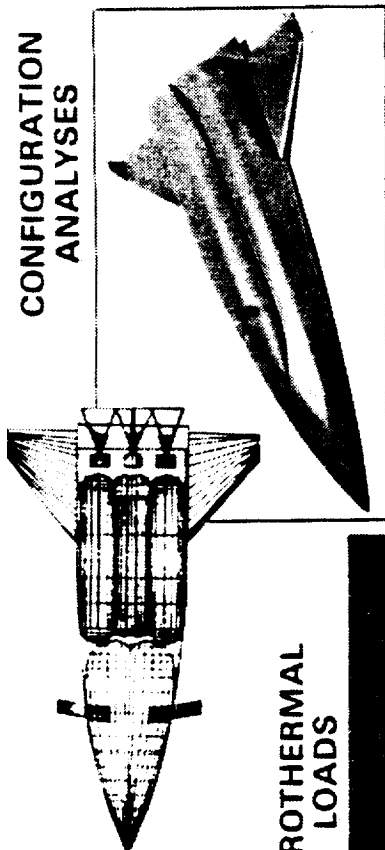
ADVANCED  
COMPUTATIONAL METHODS



AEROTHERMAL  
LOADS



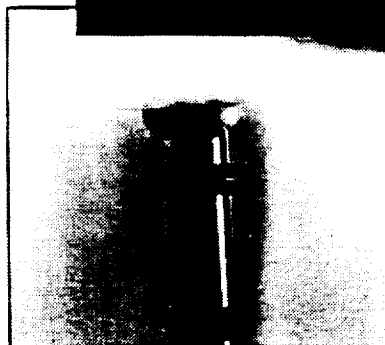
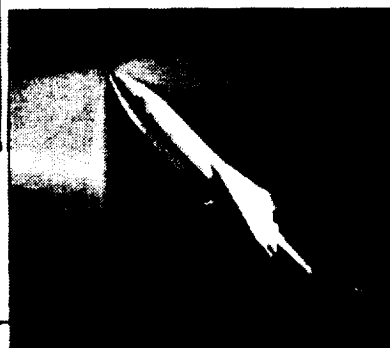
CONFIGURATION  
ANALYSES



FLIGHT DATA  
ANALYSES



HYPERSONIC  
WIND  
TUNNEL  
TESTING

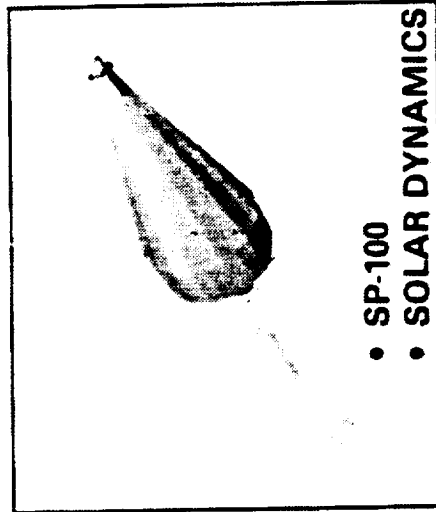


NASA

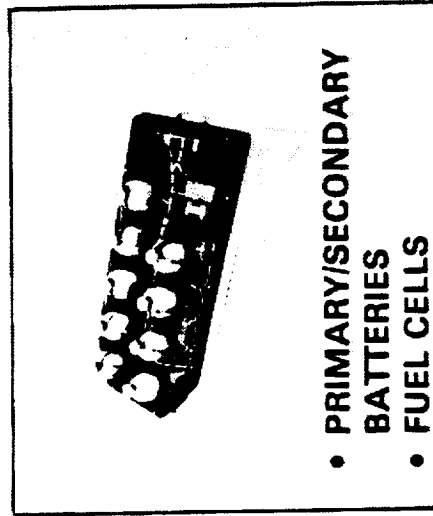
OASD  
AFB 1283 13

# SPACE ENERGY CONVERSION

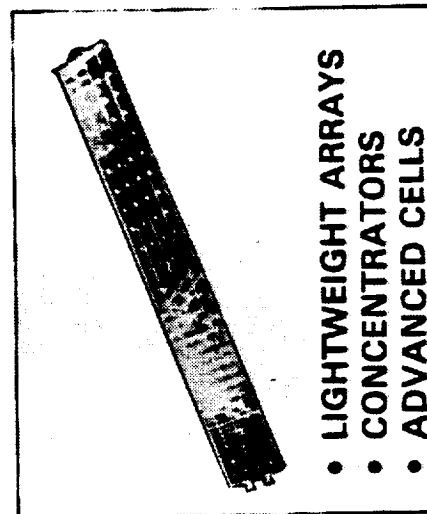
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- SP-100
- SOLAR DYNAMICS



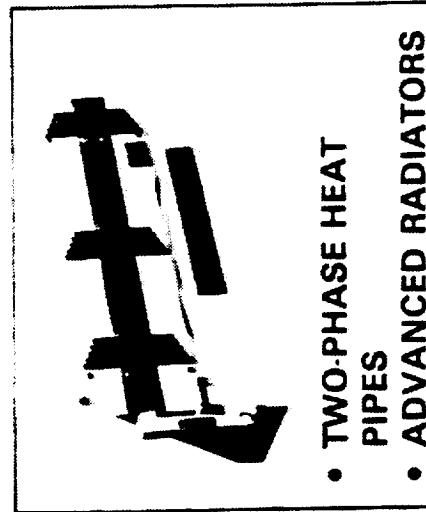
- PRIMARY/SECONDARY BATTERIES
- FUEL CELLS



- LIGHTWEIGHT ARRAYS
- CONCENTRATORS
- ADVANCED CELLS



- POWER DISTRIBUTION COMPONENTS



- TWO-PHASE HEAT PIPES
- ADVANCED RADIATORS

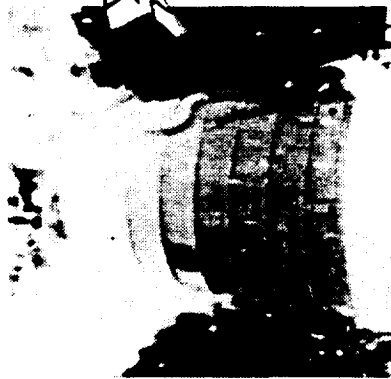
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**OASD**  
RP 85-68731

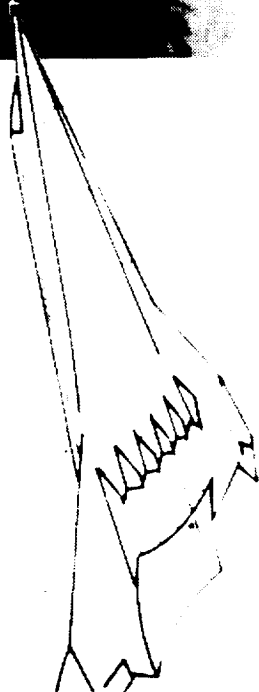


# PROPULSION

LOX/HYDROGEN



AIRBREATHING



LOX/HYDROCARBON



REUSABLE EARTH-TO-ORBIT



ELECTRIC  
PROPULSION



OTV  
PROPULSION

NASA

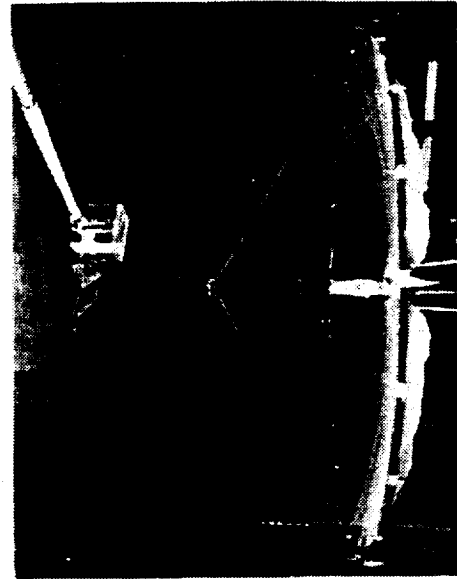
OASD  
RPB 645 (3)

# MATERIALS AND STRUCTURES

## STRUCTURAL CONCEPTS

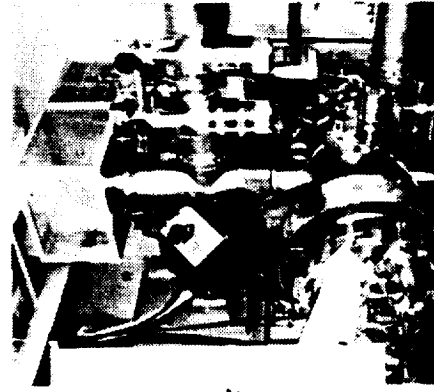


## AEROTHERMAL STRUCTURES



## DYNAMICS OF FLEXIBLE STRUCTURES

NASA



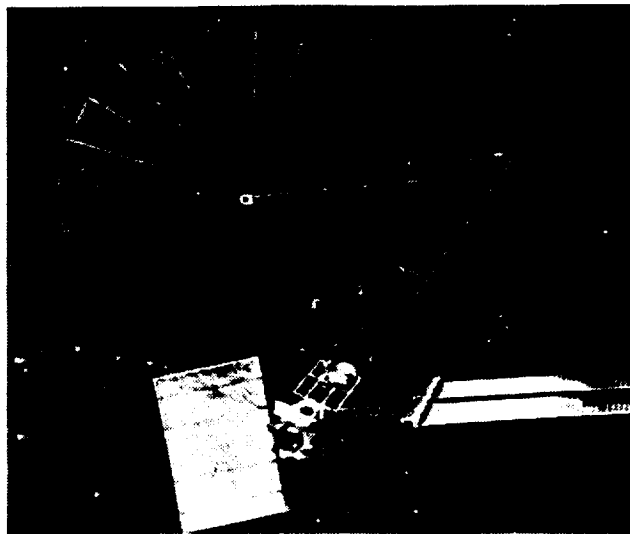
## SPACE DURABLE MATERIALS

OASI  
PMES-1208 (3)

# SPACE DATA AND COMMUNICATIONS

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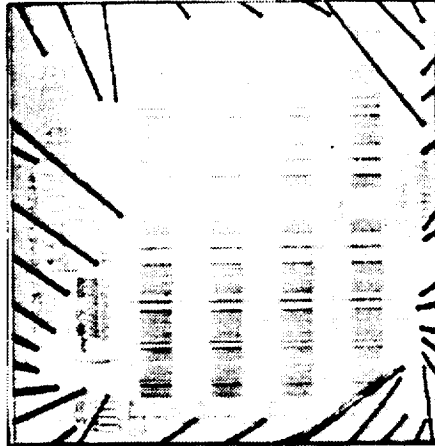
**LARGE APERTURE  
ANTENNA**



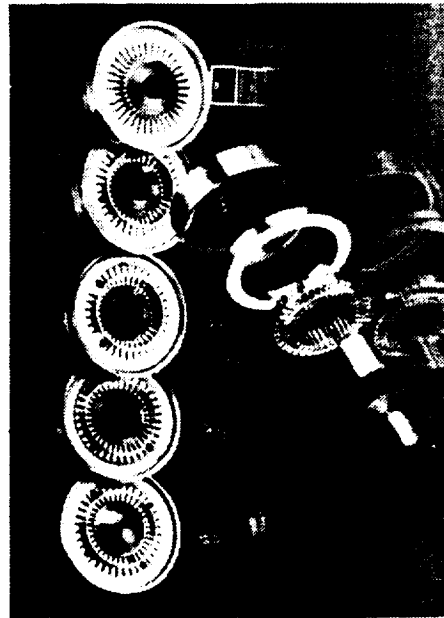
**LASER COMMUNICATIONS**



**ON-BOARD  
PROCESSING  
COMPONENTS**



**ADVANCED  
TRAVELING WAVE TUBE**



**NASA**

**QAS**  
RC86-440(3)

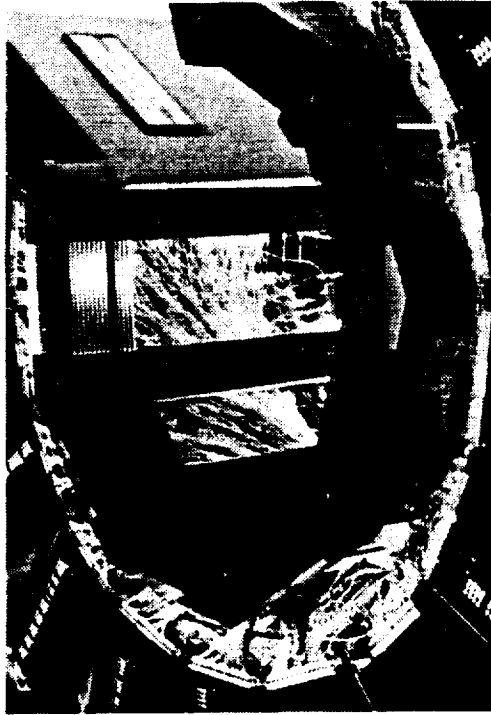
# INFORMATION SCIENCES

## REMOTE SENSING



NASA

## COMPUTER SCIENCES

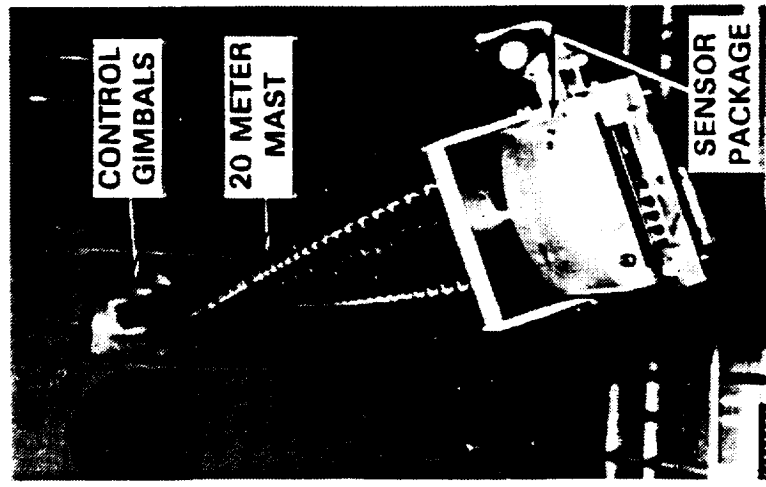


## EXPERT SYSTEMS

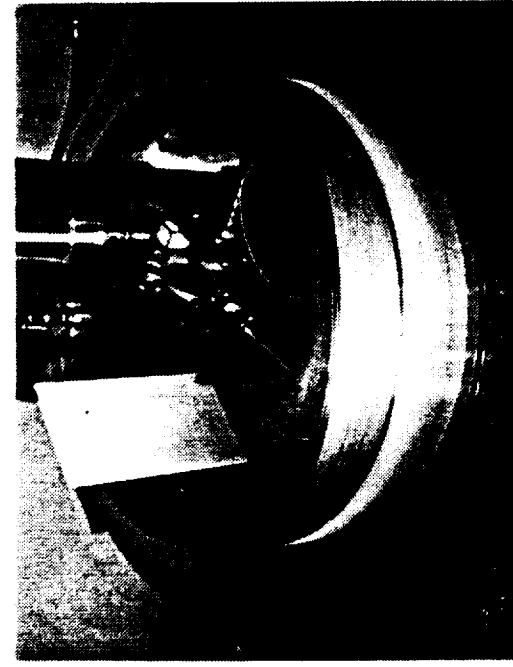
OASI  
RC86-437(3)

# CONTROLS AND GUIDANCE

BEAM DYNAMICS

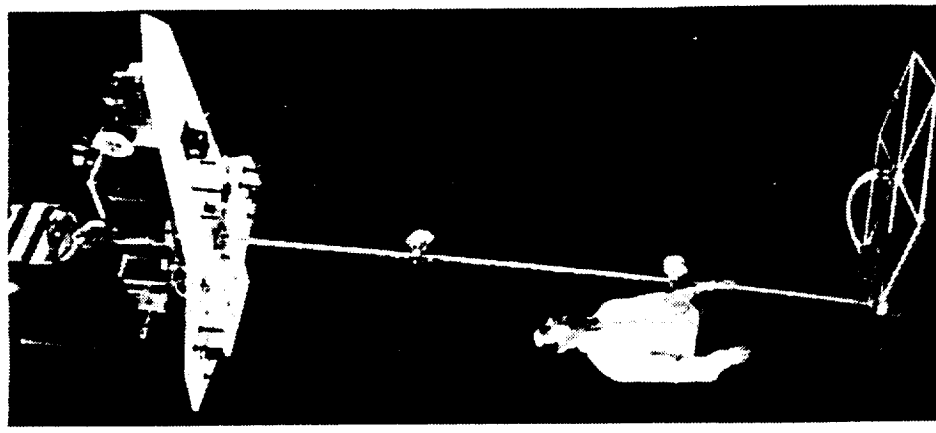


ADAPTIVE CONTROL (AFE)



LASER GUIDANCE RESEARCH

SPACECRAFT CONTROL LABORATORY EXPERIMENT

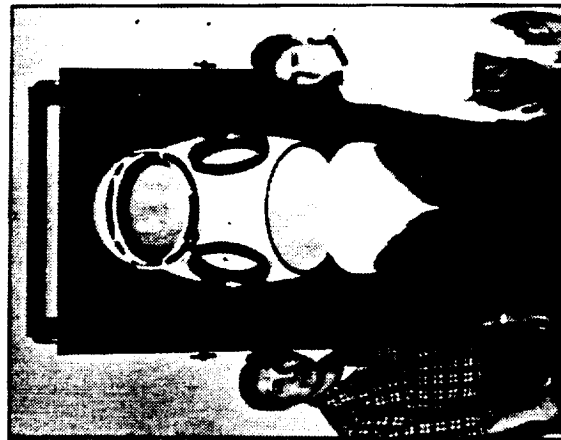


OASI  
RCB-438(3)

NASA

# HUMAN FACTORS

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SPACE  
SUIT

EVA AIDS



CREW  
STATION  
DESIGN



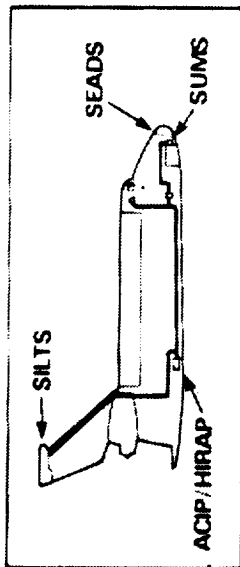
DISPLAY  
MODELING

NASA

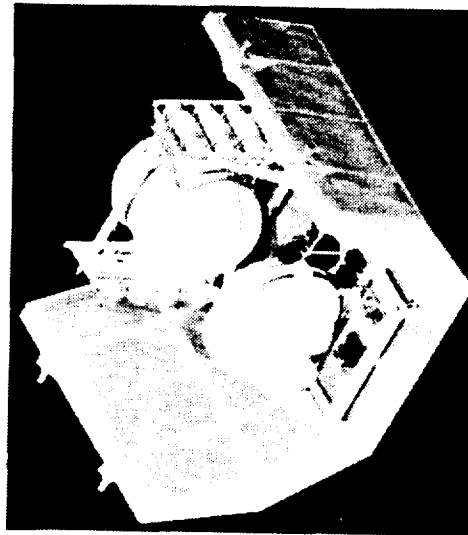
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RC86-439(3)

# SPACE FLIGHT SYSTEMS R&T

## SPACE

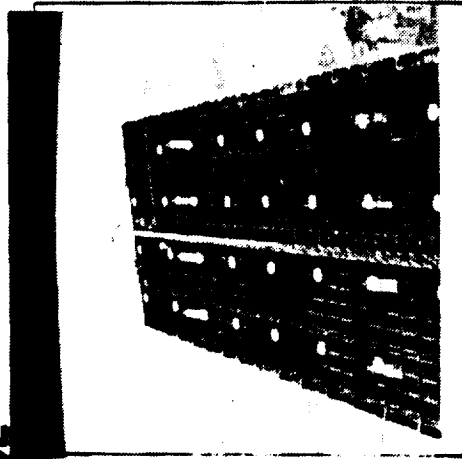


**ORBITER EXPERIMENTS  
(IOEX)**

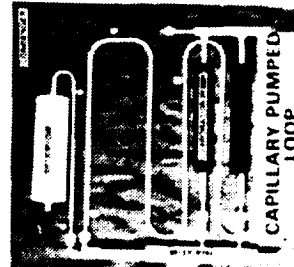


**CRYOGENIC FLUID  
MANAGEMENT**

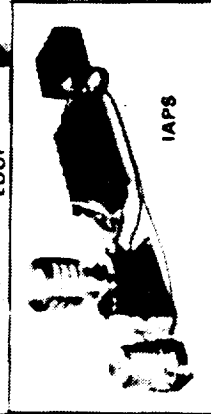
**NASA**



**SOLAR  
ELECTRIC  
PROPLUSION  
(SEP)**



**SPACE  
FLIGHT  
EXPERIMENTS**



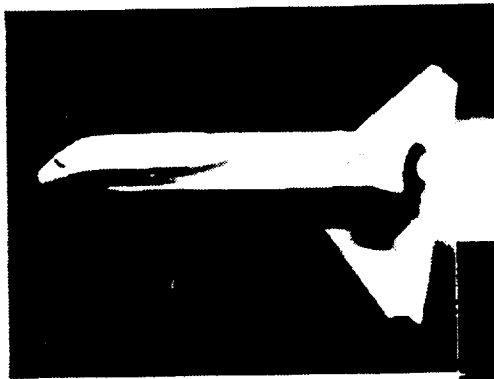
**OAST**  
PMOS 1287 (3)

# SYSTEMS ANALYSIS

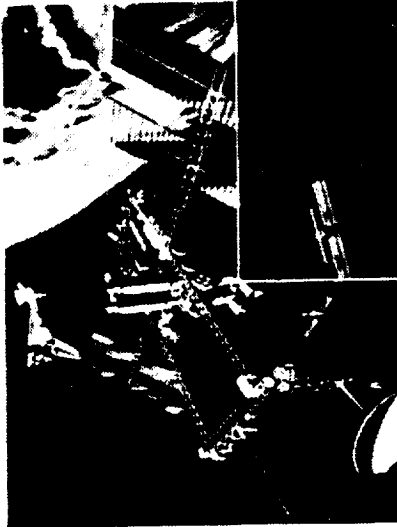
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## TECHNOLOGY FOR FUTURE SPACE SYSTEMS

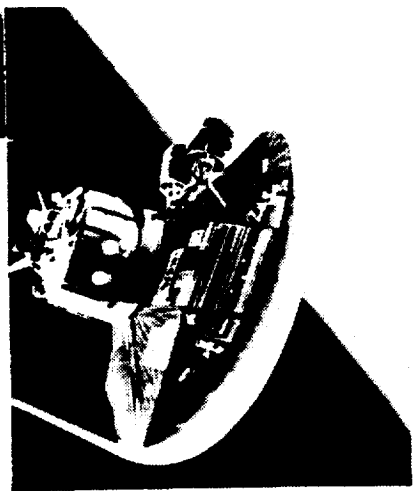
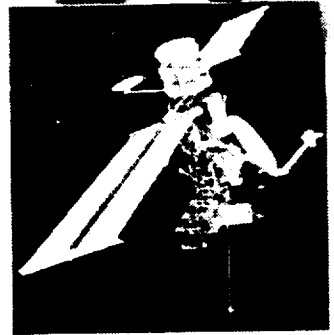
TRANSPORTATION



LARGE SPACE SYSTEMS



SPACECRAFT



NASA

OAST

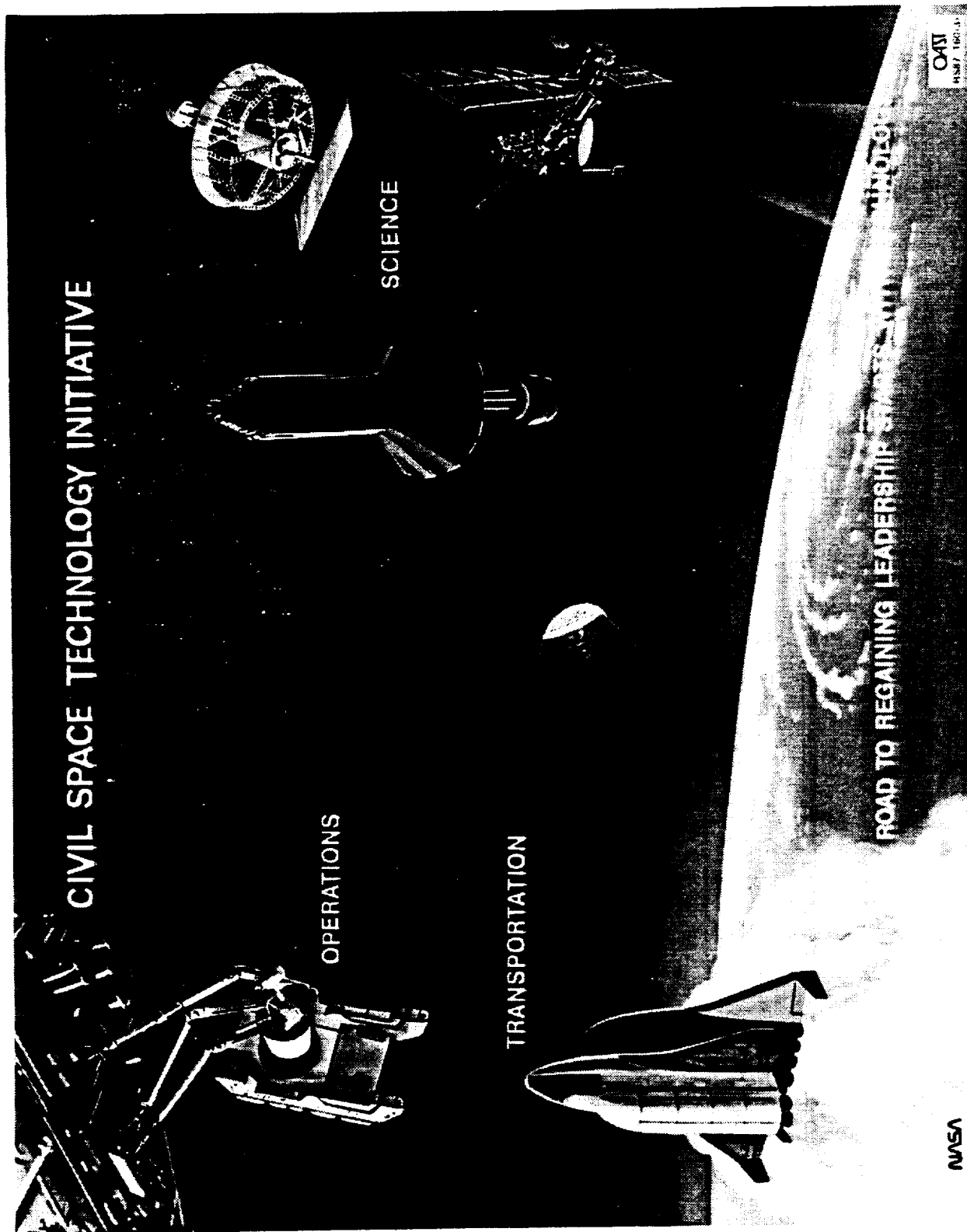


# **SPACE RESEARCH & TECHNOLOGY BASE**

~~OSI~~ ~~IN SEP 88~~

## **CANDIDATE EXAMPLES FOR FUTURE EMPHASIS**

- SOFTWARE ENGINEERING
- HIGH TEMPERATURE SUPERCONDUCTORS
- OPTICS
- COMPUTATIONAL CONTROLS
- NDE/NDI
- TECHNOLOGY FOR SELF REPAIR
- BASIC RESEARCG IN "INHERENT RELIABILITY"
- MICROSAT TECHNOLOGY
- WORLD MODELING DATA SYSTEMS



## **BACKGROUND**

~~—OASD~~

~~—IN-STEP-88~~

- THE FIRST STEP IN REVITALIZING THE NATION'S CIVIL TECHNOLOGY BASE
- WILL FILL IN GAPS IN MANY TECHNOLOGY AREAS
- FOCUSED TECHNOLOGY EFFORT, WILL RESULT IN DEMONSTRATED / VALIDATED TECHNOLOGIES

# MISSION NEEDS

~~CAST~~ ~~IN-STEP-88~~

- TRANSPORTATION TO LOW EARTH ORBIT
  - PROPULSION
  - AEROBRAKING
- OPERATIONS IN LOW EARTH ORBIT
  - AUTONOMOUS SYSTEMS
  - TELEROBOTICS
  - POWER
- SCIENCE
  - STRUCTURES
  - SENSORS
  - DATA SYSTEMS

# PATHFINDER

Transportation

Operations

Exploration

Humans-in-Space

## **PATHFINDER**

**~~OAST~~** **~~IN-STEP-88~~**

- DEVELOPS HIGH LEVERAGE TECHNOLOGIES FOR PILOTED AND ROBOTIC SOLAR SYSTEM EXPLORATION
- CRITICAL ELEMENT OF THE PRESIDENT'S SPACE POLICY
- LONG-TERM PROGRAM, PROVIDING BOTH RESEARCH AND DEMONSTRATIONS
- NECESSARY TO MAINTAIN U.S. LEADERSHIP IN SPACE

# STRATEGY

~~OST~~ ~~IN-STEP 88~~

- VALIDATE TECHNOLOGY FOCUSED ON ENABLING AND ENHANCING NEW MISSIONS

## LONG RANGE PLAN

- EMPHASIZE HEALTHY AND COMPLETE CSTI AND PATHFINDER PROGRAMS
- RESPOND TO EVOLVING NEW MISSION CONCEPTS
- REFINE AND ACCELERATE TECHNOLOGY DEVELOPMENT AND VALIDATION IN RESPONSE TO AGENCY DECISION ON BOLD NEW INITIATIVES

# UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

~~CAST~~ ~~IN-SHEP-88~~

- INTEGRAL PART OF STRATEGY TO REBUILD R&T BASE
  - INCREASE NUMBER OF ENGINEERING GRADUATES
  - INCREASE INVOLVEMENT OF UNIVERSITIES IN CIVIL SPACE PROGRAM
- LONG TERM FUNDING ENCOURAGES UNIVERSITY COMMITMENT
- UNIVERSITY INVOLVEMENT ADDS VALUE
  - SPACE R&T
    - INNOVATIVE/CREATIVE APPROACHES
    - PARTICIPATION FROM WIDE RANGE OF ENGINEERING AND SCIENTIFIC FIELDS
  - UNIVERSITY
    - IMPROVES CURRICULA
    - GREATER RELEVANCE OF RESEARCH TO CIVIL SPACE NEEDS



# UNIVERSITY SPACE ENGINEERING RESEARCH PROGRAM

**CASH** **IN-SHEP-88**

## NINE CENTERS SELECTED FOR FY 1988

UNIVERSITY OF ARIZONA	CENTER FOR UTILIZATION OF LOCAL PLANETARY RESOURCES
UNIVERSITY OF CINCINNATI	HEALTH MONITORING TECHNOLOGY CENTER FOR SPACE PROPULSION SYSTEMS
UNIVERSITY OF COLORADO, BOULDER	CENTER FOR SPACE CONSTRUCTION
UNIVERSITY OF IDAHO	VERY LARGE SCALE INTEGRATED HARDWARE ACCELERATION CENTER FOR SPACE RESEARCH
MASSACHUSETTS INSTITUTE OF TECHNOLOGY	CENTER FOR SPACE ENGINEERING RESEARCH FOCUSED ON CONTROLLED STRUCTURES TECHNOLOGY
UNIVERSITY OF MICHIGAN	CENTER FOR NEAR-MILLIMETER WAVE COMMUNICATION
NORTH CAROLINA STATE AT RALEIGH & NORTH CAROLINA AGRICULTURAL & TECHNICAL STATE UNIVERSITY	MARS MISSION RESEARCH CENTER
PENNSYLVANIA STATE UNIVERSITY	CENTER FOR SPACE PROPULSION ENGINEERING
RENSSELAER POLYTECHNIC INSTITUTE	INTELLIGENT ROBOTIC SYSTEMS FOR SPACE EXPLORATION

# STRATEGY

~~0-A-S-I~~ ~~IN-STEP-88~~

- EXPAND UNIVERSITY PROGRAMS

## LONG RANGE PLAN

- GROWTH FOR NINE INCUMBENT UNIVERSITY ENGINEERING RESEARCH CENTERS AWARDED IN APRIL, 1988
- ADD NEW AREAS OF PROGRAMMATIC INTEREST
- BROADEN UNIVERSITY SUPPORT TO INCLUDE INDIVIDUAL INNOVATION IN RESEARCH

## **IN-SPACE EXPERIMENTS IN OAST**

~~OAST~~ ~~IN-SHEP 88~~

- **IN-SPACE EXPERIMENTS HAVE ALWAYS BEEN PART OF OAST'S PROGRAM**
  - TO OBTAIN DATA THAT CAN NOT BE ACQUIRED ON THE GROUND
  - TO DEMONSTRATE FEASIBILITY OF CERTAIN ADVANCED TECHNOLOGIES
- **CONDUCTING TECHNOLOGY EXPERIMENTSS IN SPACE IS A VALUABLE AND COST EFFECTIVE WAY TO INTRODUCE ADVANCED TECHNOLOGY INTO FLIGHT PROGRAMS**
- **THE SHUTTLE HAS DEMONSTRATED THE FEASIBILITY AND TIMELY BENEFITS OF CONDUCTING HANDS-ON EXPERIMENTS IN SPACE**
- **SPACE STATION WILL BE A PERMANENT LABORATORY IN SPACE AND WILL PROVIDE LOGICAL AND EVOLUTIONARY EXTENSION OF GROUND BASED R&T IN SPACE**

# IN-SPACE EXPERIMENTS PLANNING

~~OAST~~ ~~IN-STEP-88~~

ASEB PANEL ON NASA'S R&T PROGRAM	JUNE	1983
INDUSTRY/DOD WORKSHOP	FEB	1984
ADMINISTRATOR'S POLICY STATEMENT	APRIL	1984
ASEB PANEL ON IN-SPACE ENGINEERING AND TECHNOLOGY DEVELOPMENT	MAY	1985
OAST IN-SPACE TECHNOLOGY WORKSHOP	OCT	1985
INITIATION OF IN-REACH/OUT-REACH PROGRAMS	OCT	1985
SSTAC AD HOC COMMITTEE ON THE USE OF SPACE STATION FOR IN-SPACE ENGINEERING R&T	AUG	1987
SPACE STATION OPERATIONS TASK FORCE	OCT	1987
NASA MANAGEMENT STUDY GROUP (NMSG - 24)	DEC	1987
NASA CENTER SCIENCE ASSESSMENT TEAM	MAY	1988

## **ADVISORY GROUP RECOMMENDATIONS**

~~OAST~~ ~~IN-STEP 88~~

..."NASA SHOULD PROVIDE ACCESS TO SPACE FOR EXPERIMENTAL PURPOSES AS A NATURAL EXTENSION OF AEROSPACE FACILITIES..."  
...AN EVOLUTIONARY PROGRAM OF ON-ORBIT RESOURCE EQUIVALENT TO ... THE WIND TUNNELS"...

ASEB, 1983

..."NASA SHOULD BETTER EXPLOIT THOSE SPACE FACILITIES THAT ARE UNIQUE ..... THE SHUTTLE AND THE SPACE STATION FOR THE DEVELOPMENT OF TECHNOLOGY FOR NASA, DOD, AND THE INDUSTRY"...

DOD/INDUSTRY (HEARTH) WORKSHOP, 1984

..."OAST SHOULD PROVIDE THE LEADERSHIP.....TO SUPPORT THE ENGINEERING TECHNOLOGY NEEDS OF THE USER INDUSTRY, OTHER GOVERNMENT AGENCIES, AS WELL AS ITS OWN FOR ALL IN-SPACE ENGINEERING R&T"...

ASEB, 1985

# NASA POLICY ON ROLE OF SPACE TECHNOLOGY

~~OAST~~ ~~IN-STEP 88~~

... "IT WILL BE NASA'S POLICY TO SUPPORT THE DOD AND SPACE  
INDUSTRY THROUGH COMPETITIVE R&T PROGRAMS JUST AS WE  
DO IN AERONAUTICS" ...

... "WE CAN BE PARTICULARLY EFFECTIVE IN ESTABLISHING  
CLOSER TIES WITH INDUSTRY AND THAT IS THE USE OF THE SHUTTLE  
FOR IN-SPACE EXPERIMENTS... WHICH WILL LEAD QUITE NATURALLY  
TO USING THE SPACE STATION FOR TECHNOLOGY AND ENGINEERING  
EXPERIMENTS" ...

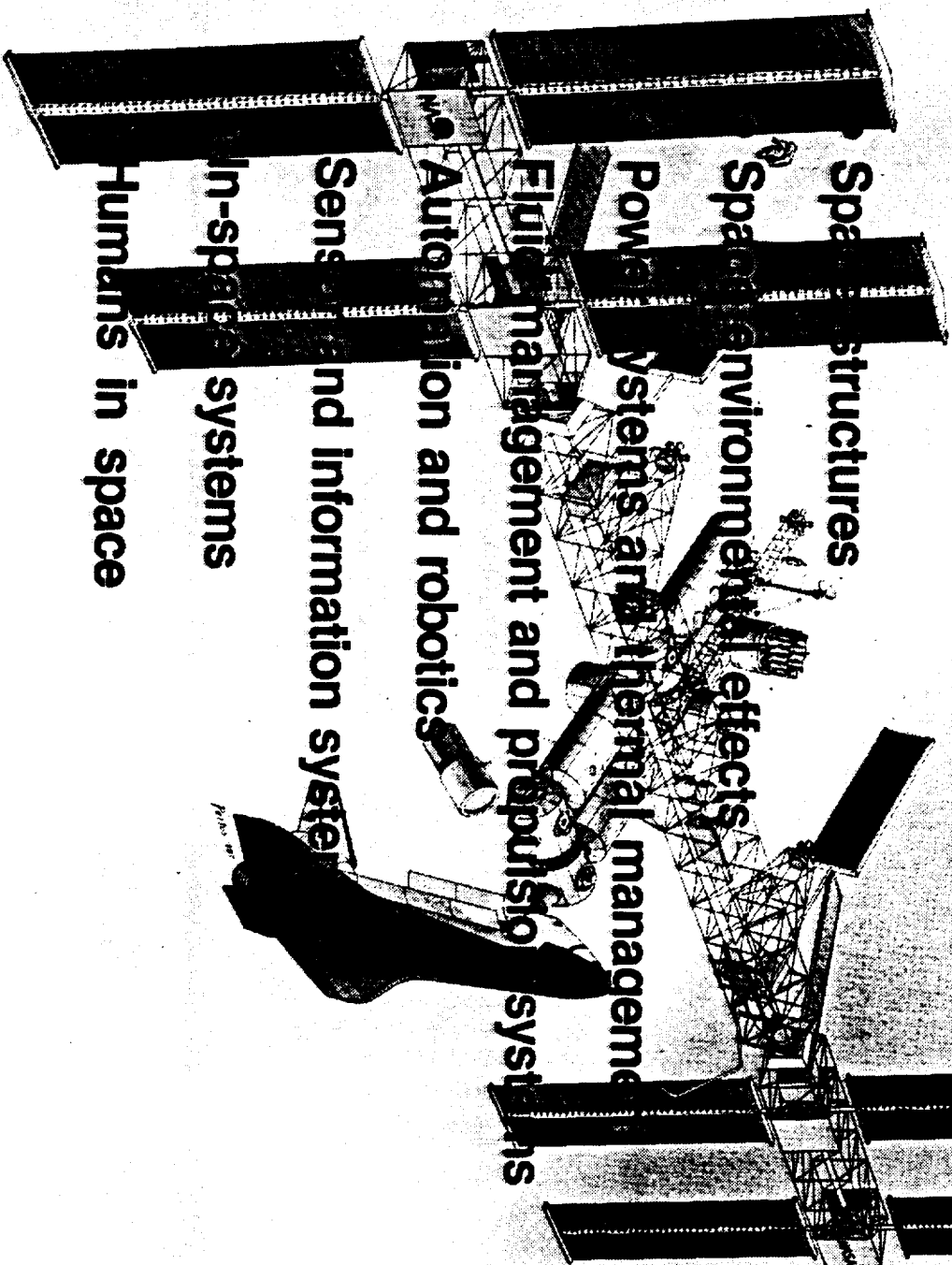
... "TO BEGIN IMPLEMENTING THIS POLICY, I HAVE ASKED ..(OAST)..  
TO INCREASE OUR EMPHASIS ON IN-FLIGHT EXPERIMENTS" ...

MEMORANDUM FROM THE ADMINISTRATOR

APRIL 3, 1984

# USING SPACE FOR TECHNOLOGY DEVELOPMENT

0487



## IN-SPACE EXPERIMENTS INITIATIVE - PHASE I

- FLIGHT OPPORTUNITY RESTORED
- INITIATE MORE VIGOROUS PROGRAM ON SHUTTLE AND ELVS
  - OBTAIN DATA THAT CAN NOT BE OBTAINED ON THE GROUND
  - VALIDATE ADVANCED TECHNOLOGIES FOR EARLY USE IN FLIGHT PROJECTS
- GET A RUNNING START ON SPACE STATION
  - GEAR UP NASA, INDUSTRY, UNIVERSITY ACTIVITY
  - CONDUCT SPACE STATION PRECURSOR EXPERIMENTS



# **IN-SPACE TECHNOLOGY EXPERIMENTS PROGRAM**

~~0497~~ ~~IN-SHEP-88~~

- **NASA EXPERIMENTS**

- ARISE FROM THE R&T BASE OR FOCUSED PROGRAMS
- INCLUDE PRESENTLY ONGOING EXPERIMENTS

- **INDUSTRY/UNIVERSITY EXPERIMENTS**

- FOLLOWING THROUGH ON OUR COMMITMENTS IN THE OUT-REACH PROGRAM

- **INTERNATIONAL EXPERIMENTS**

- COOPERATIVE ACTIVITIES WITH OUR ALLIES

# **NASA IN-SPACE TECHNOLOGY EXPERIMENTS**

~~049T~~ ~~IN-STEP 88~~

- **INCORPORATES PRESENTLY ON-GOING IN-SPACE R&T PROGRAM**

- ORBITER EXPERIMENTS PROGRAM (OEX)
- LONG DURATION EXPOSURE FACILITY (LDEF)
- LIDAR IN-SPACE TECHNOLOGY EXPERIMENT (LITE)
- ARCJET AUXILIARY PROPULSION SYSTEM
- EXPERIMENTS SELECTED FROM IN-REACH SOLICITATION

- **FUTURE EXPERIMENTS WILL CONTINUE TO ARISE AS A NATURAL EXTENSION OF R&T BASE AND FOCUSED PROGRAMS**

- CIVIL SPACE TECHNOLOGY INITIATIVE (CSTI)
- PATHFINDER

# INDUSTRY/UNIVERSITY IN-SPACE EXPERIMENTS

~~OAST~~ ~~IN-STEP-88~~

- PROVIDE ACCESS TO SPACE FOR INDUSTRY AND UNIVERSITIES TO DEVELOP SPACE TECHNOLOGY
- ENTHUSIASTIC RESPONSE OF AEROSPACE COMMUNITY TO OUT-REACH SOLICITATION

45

- OAST HAS COMMITTED TO AEROSPACE COMMUNITY TO SERVE AS CONDUIT FOR TECHNOLOGY DEVELOPMENT IN SPACE
  - PERIODIC RESOLICITATIONS TO INDUSTRY/UNIVERSITY COMMUNITY FOR EXPERIMENT DEFINITION, DEVELOPMENT, AND FLIGHT

~~OASD~~

~~IN-SHEP-88~~

## INTERNATIONAL IN-SPACE EXPERIMENTS

- PROMOTES COOPERATION WITH ALLIES
- LEVERAGES TECHNOLOGY DEVELOPMENT BY OTHERS IN KEY AREAS
- LEVERAGES AND HUSBANDS SCARCE FLIGHT OPPORTUNITIES

## **IN-SPACE EXPERIMENTS INITIATIVE - PHASE II**

~~0497~~ ~~IN-SHIP 88~~

- ROUTINE OPERATIONS IN LOW EARTH ORBIT WILL INITIATE ERA OF BOLD NEW INITIATIVES
  - NEED FOR TECHNOLOGY DEMONSTRATIONS FOR ENABLING TECHNOLOGIES WILL INCREASE
  - THE RANGE OF TECHNOLOGIES TO BE DEMONSTRATED IN SPACE WILL INCREASE
  - SPACE STATION WILL PROVIDE THE FACILITY FOR SIMPLER, FASTER ACCESS TO SPACE
  - SPACE STATION WILL ENABLE EXPERIMENTS NEEDING LONG-TERM HUMAN INTERACTION

- EXPERIMENTS PLANNED AND DEFINED FOR SPACE STATION DURING PHASE I WILL ENTER HARDWARE DEVELOPMENT STAGE

# SUMMARY

~~04ST~~

~~IN-SHEP-88~~

- TECHNICAL NEED IDENTIFIED 1983
- PLANNING COMPLETE 1983-86
- COMMITMENTS MADE 1986-88

48

- INDUSTRY / UNIVERSITIES (VIA OUT-REACH)
- CENTERS (VIA IN-REACH)
- INTERNATIONAL COMMUNITY
- OPPORTUNITY FOR SPACE FLIGHT RESTORED
  - SHUTTLE, ELV MANIFESTING
  - SPACE STATION PLANNING

# STRATEGY

~~04-91~~

~~IN-SHEP-88~~

- ENSURE INNOVATIVE R&T BASE
- VALIDATE TECHNOLOGY FOCUSED ON ENABLING  
NEW MISSIONS
- BUILD STRONGER LINKAGES TO EFFECTIVELY  
TRANSFER NEW TECHNOLOGIES TO USERS
- EXPAND UNIVERSITY PROGRAMS
- STEP UP TO COMMITMENT AS LEADER FOR  
TECHNOLOGY DEVELOPMENT ON SPACE STATION

# SUMMARY

~~OAST~~

~~IN-SPEP-88~~

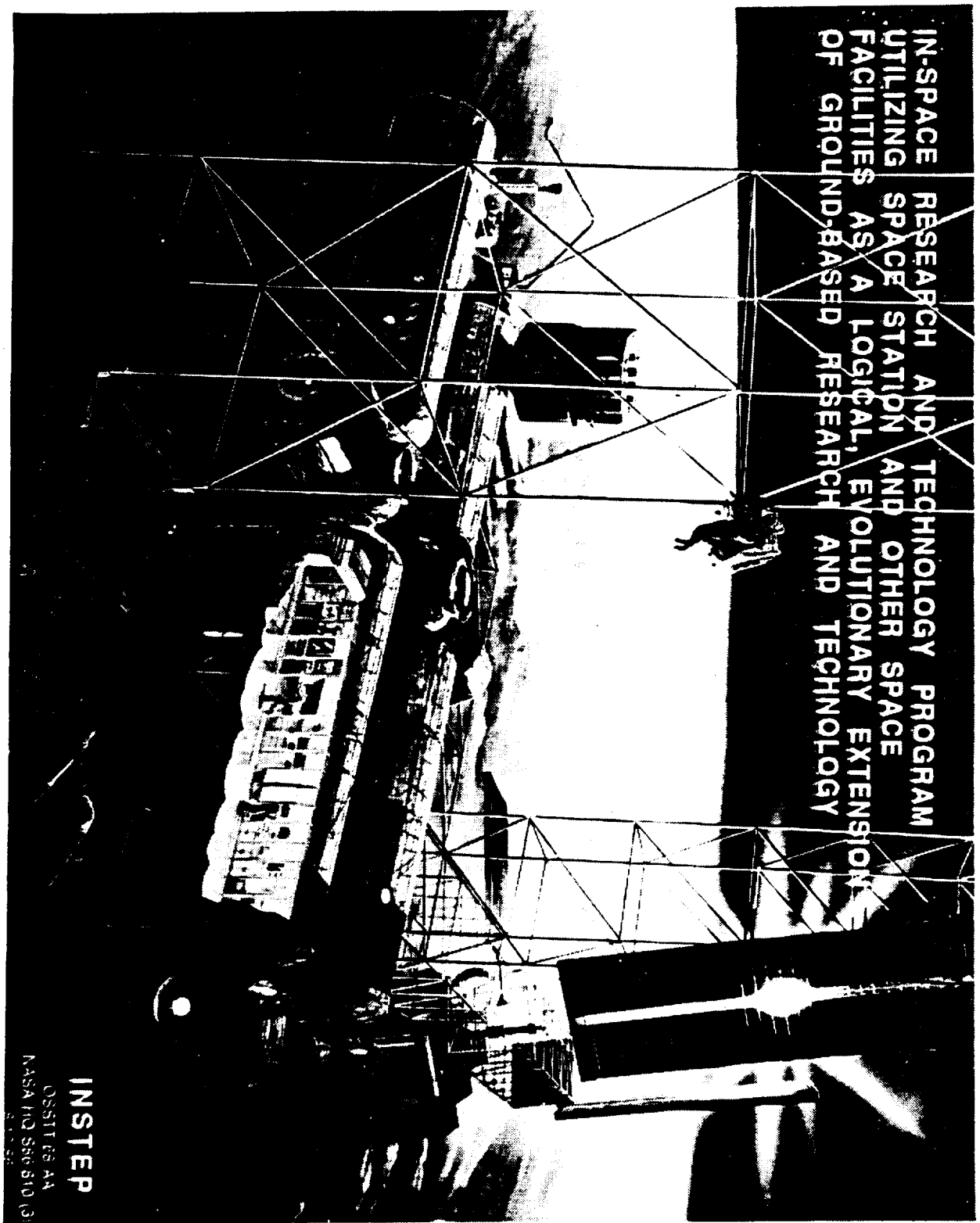
## SPACE R&T: A FIVE YEAR OUTLOOK

50

- EQUITABLE AGENCY TECHNOLOGY INVESTMENT ESTABLISHED
- OAST IN TECHNOLOGY LEADERSHIP ROLE FOR AGENCY
- COOPERATIVE TECHNOLOGY HAND-OFF AGREEMENTS ESTABLISHED WITH USERS
- COORDINATION WITH NATIONAL SPACE SECTORS WELL ESTABLISHED
- OAST RECOGNIZED AS NATIONAL FOCAL POINT FOR IN-SPACE TECHNOLOGY DEVELOPMENT



IN-SPACE RESEARCH AND TECHNOLOGY PROGRAM  
UTILIZING SPACE STATION AND OTHER SPACE  
FACILITIES AS A LOGICAL, EVOLUTIONARY EXTENSION  
OF GROUND-BASED RESEARCH AND TECHNOLOGY



INSTEP

OSSTT 68-44  
NASA HQ S66-510 (3)

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# IN-SPACE TECHNOLOGY EXPERIMENT PROGRAM

BY JACK LEVINE  
DIRECTOR,  
FLIGHT PROJECTS DIVISION

and  
JON S. PYLE  
MANGER,  
IN-REACH & OUT-REACH PROGRAMS

OFFICE OF AERONAUTICS & SPACE TECHNOLOGY

# CURRENT SPACE FLIGHT EXPERIMENTS

0457

IN-SHEEP

88

WORKSHOP

<u>FLIGHT EXPERIMENTS</u>	<u>HQ</u>	<u>LEAD CENTER</u>
LONG DURATION EXPOSURE FACILITY	JOHN LORIA	- LANGLEY
ORBITER EXPERIMENTS	RICHARD GUALDONI	- JOHNSON
LIDAR IN-SPACE TECHNOLOGY EXPERIMENT	RICHARD GUALDONI	- LANGLEY
AEROASSIST FLIGHT EXPERIMENT	JOHN SMITH	- MARSHALL
ARCJET FLIGHT EXPERIMENT	JOHN LORIA	- LEWIS
TELEROBOT INTELLIGENT INTERFACE FLIGHT EXPERIMENT	RICHARD GUALDONI	- JPL
CRYOGENIC FLUID MANAGEMENT FLIGHT EXPERIMENT	JOHN LORIA	- LEWIS
IN-REACH (NASA TECHNOLOGY EXPERIMENTS)	JOHN PYLE	
OUT-REACH (INDUSTRY/UNIVERSITY TECHNOLOGY EXPERIMENTS)	JOHN PYLE	

# LDEF

## LONG DURATION EXPOSURE FACILITY

### OBJECTIVES:

- DETERMINE LONG-TERM SPACE EXPOSURE EFFECTS ON MATERIALS, COATINGS, & OPTICS
- MEASURE SPACE ENVIRONMENTAL PHENOMENA OVER EXTENDED TIME

55

### STATUS:

- 34 EXPERIMENTS ADVERSELY AFFECTED BY LDEF RECOVERY DELAY
- 23 EXPERIMENTS EITHER IMPROVED OR NOT AFFECTED
- LDEF STRUCTURE AVAILABLE FOR STUDY OF ENVIRONMENTAL EROSION & DEBRIS IMPACT
- SCHEDULED FOR RETRIEVAL - NOVEMBER 1989

### LEAD CENTER CONTACT:

- ROBERT L. JAMES, JR.  
LANGLEY RESEARCH CENTER  
PHONE NO. (804) 865-4987

# OEX

## ORBITER EXPERIMENT PROGRAM

~~04-51~~

~~IN-STEP 88 WORKSHOP~~

### OBJECTIVES:

- OBTAIN BASIC AEROTHERMODYNAMIC & ENTRY ENVIRONMENT DATA FROM R&D INSTRUMENTATION INSTALLED IN SPACE SHUTTLE ORBITER
- FLIGHT-VALIDATE GROUND TEST RESULTS TO IMPROVE BASIS FOR DESIGN OF ADVANCED SPACECRAFT

### STATUS:

- DATA COLLECTION ON-GOING SINCE 1985 - WILL CONTINUE INTO 1990'S
- SOME EXPERIMENTS STILL TO BE DESIGNED & DEVELOPED

### LEAD CENTER CONTACT:

- ROBERT SPANN  
JOHNSON SPACE CENTER  
PHONE # (713) 483-3022

# LITE

## LIDAR IN-SPACE TECHNOLOGY EXPERIMENT

### OBJECTIVE:

- EVALUATE CRITICAL ATMOSPHERIC PARAMETERS & VALIDATE OPERATION OF A SOLID-STATE LIDAR SYSTEM FROM A SPACEBORNE PLATFORM, MEASURING:
  - CLOUD DECK ALTITUDES
  - PLANETARY BOUNDARY-LAYER HEIGHTS
  - STRATOSPHERIC & TROPOSPHERIC AEROSOLS
  - ATMOSPHERIC TEMPERATURE & DENSITY (10KM TO 40KM)

### STATUS:

- LASER TRANSMITTER MODULE, CASSEGRAIN TELESCOPE, & ENVIRONMENTAL MONITORING SYSTEM IN DEVELOPMENT
- FLIGHT MANIFESTED FOR 1993

### LEAD CENTER CONTACT:

- RICHARD R. NELMS  
LANGLEY RESEARCH CENTER  
PHONE NO. (804) 865-4947

# AFM

## AEROASSIST FLIGHT EXPERIMENT

**G-4-S-T**

# 88 WORKSHOP

## OBJECTIVE:

- INVESTIGATE CRITICAL VEHICLE DESIGN & ENVIRONMENTAL TECHNOLOGIES APPLICABLE TO THE DESIGN OF AEROASSISTED SPACE TRANSFER VEHICLES

**STATUS:**

- PHASE B DEFINITION COMPLETE
- EXPERIMENT/INSTRUMENT COMPLEMENT ESTABLISHED
- PRELIMINARY DESIGN INITIATED

**LEAD CENTER CONTACT:**

- **LEON B. ALLEN**  
MARSHALL SPACE FLIGHT CENTER  
PHONE NO. (205) 544-1917



# ARCJET FLIGHT EXPERIMENT

~~0431~~

~~IN-SHEP 83 WORKSHOP~~

## OBJECTIVES:

- ASSESS ARCJET AUXILIARY PROPULSION SYSTEM OPERATION IN SPACE ENVIRONMENT
  - HY DRAZINE PROPELLANT
  - 1.4 KW, 50 MLB THRUST, Isp 450
- EVALUATE PLUME EFFECTS & THRUSTER/THERMAL INTERACTIONS ON A COMMERCIAL COMMUNICATIONS SATELLITE

59

## STATUS:

- PRELIMINARY DESIGN & ARCJET COMPONENT DEVELOPMENT COMPLETED
- FLIGHT HARDWARE DESIGN, DEVELOPMENT & TESTING SCHEDULED TO START IN 1989
- FLIGHT TEST TENTATIVELY PLANNED FOR 1991

## LEAD CENTER CONTACT:

- JERRI S. LING  
LEWIS RESEARCH CENTER  
PHONE NO. (216) 433-2841

# TRIIFEX

## TELEROBOTIC INTELLIGENT INTERFACE

### FLIGHT EXPERIMENT

~~04-9-1~~

~~IN-STEP 88 WORKSHOP~~

#### OBJECTIVES:

- EVALUATE & VALIDATE TELEOPERATION OF A ROBOTIC MANIPULATOR UNDER CONDITIONS OF MICRO-G & COMMUNICATION TIME DELAYS
- VALIDATE ADVANCED SPACE TELEROBOT CONTROLS INCLUDING HIGH-FIDELITY HYBRID POSITION & FORCE CONTROL TECHNIQUES

86

#### STATUS:

- CONCEPTUAL DESIGN IN PROGRESS AT JPL
- DEVELOPMENT & INTEGRATION SCHEDULED TO START IN LATE 1988
- FLIGHT TEST PLANNED IN COMBINATION WITH GERMAN ROTEX EXPERIMENT ON SPACELAB D-2 MISSION (1991)

#### LEAD CENTER CONTACT:

- DANIEL KERRISK  
JET PROPULSION LABORATORY  
PHONE NO. (818) 354-2566

# CFMFE

## CRYOGENIC FLUID MGMT FLIGHT EXP.

~~GA-91~~

~~IN-SHEEP-88~~ ~~WORKSHOP~~

### OBJECTIVES:

- DEVELOP TECHNOLOGY REQUIRED FOR EFFICIENT STORAGE, SUPPLY & TRANSFER OF SUBCRITICAL CRYOGENIC LIQUIDS IN LOW-GRAVITY SPACE ENVIRONMENT
- FLIGHT VALIDATE NUMERICAL MODELS OF THE PHYSICS INVOLVED

### STATUS:

- CONTRACTOR FEASIBILITY STUDIES CURRENTLY UNDER WAY
- 1992 NEW START PROPOSED

### LEAD CENTER CONTACT:

- E. PAT SYMONS  
LEWIS RESEARCH CENTER  
PHONE NO. (216) 433-2853

# PROGRAM OBJECTIVES

- PROVIDE FOR IN-SPACE FLIGHT RESEARCH  
EVALUATION & VALIDATION OF ADVANCED  
SPACE TECHNOLOGIES

## *OUT-REACH PROGRAM*

- INDUSTRY/UNIVERSITY FLIGHT  
TECHNOLOGY EXPERIMENTS

## *IN-REACH PROGRAM*

- NASA FLIGHT TECHNOLOGY  
EXPERIMENTS

# IN-REACH EXPERIMENTS

~~0-1-8-1~~

~~IN-SHEP-88-MOBIKSHOP~~

June 1986

LETTER TO CENTERS REQUESTING PROPOSED  
IN-SPACE TECHNOLOGY FLIGHT EXPERIMENTS

Aug. 1986

58 FLIGHT EXPERIMENT PROPOSALS FROM  
NASA CENTERS

Jan. 1987

COMPLETED EVALUATION OF PROPOSALS

Apr. 1987

ADVISORY COMMITTEE REVIEW & PRIORITIZATION  
OF PROPOSALS

Jul. 1987

SELECTION OF 6 DEFINITION & 1 DEVELOPMENT EXP.

- SPACE STATION STRUCTURAL CHARACTERIZATION
- LASER COMMUNICATION FLIGHT EXPERIMENT
- DEBRIS COLLISION SENSOR
- LASER IN-SPACE SENSOR EXPERIMENT
- CONTAMINATION FLIGHT EXPERIMENT
- EFFECT OF SPACE ENVIRONMENT ON THIN-FOIL MIRRORS
- THERMAL ENERGY STORAGE TEST EXPERIMENT

# OUT-REACH EXPERIMENTS

~~OUT-REACH~~

~~IN-STEP 88 WORKSHOP~~

Dec. 1985

IN-STEP 85 WORKSHOP

Oct. 1986

REQUEST FOR INDUSTRY/UNIVERSITY PROPOSALS

Jan. 1987

231 PROPOSALS FOR IN-SPACE EXPERIMENTS  
(140 FROM INDUSTRY & 91 FROM UNIVERSITIES)

84

Sept. 1987

SELECTED 5 PROPOSALS FOR DEVELOPMENT OF  
FLIGHT EXPERIMENT HARDWARE

- TANK PRESSURE CONTROL EXPERIMENT  
BOEING AEROSPACE COMPANY/ LeRC
- MID-DECK 0-G DYNAMICS EXPERIMENT  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY/LaRC
- INVESTIGATION OF SPACECRAFT GLOW  
LOCKHEED MISSILE & SPACE COMPANY/JSC
- HEAT PIPE THERMAL PERFORMANCE  
HUGHES AIRCRAFT COMPANY/GSFC
- EMULSION CHAMBER TECHNOLOGY EXPERIMENT  
UNIVERSITY OF ALABAMA IN HUNTSVILLE/MSFC

Sept. 1987

SELECTED 36 PROPOSALS FOR DEFINITION OF  
FLIGHT TECHNOLOGY EXPERIMENTS

- STUDIES TO BE COMPLETED IN SEPT. 1989
- SOLICITATION FOR DEVELOPMENT OF FLIGHT  
HARDWARE OPEN TO ENTIRE COMMUNITY

# FIRST SOLICITATION REVIEW

## OBSERVATIONS

- SIGNIFICANT EXPENDITURE BY INDUSTRY & UNIVERSITIES (231 PROPOSALS)
- APPROX. 250 NASA SCIENTISTS & TECHNOLOGISTS INVOLVED IN TECHNICAL EVALUATIONS
- NEW SOLICITATION BETWEEN DEFINITION & DEVELOPMENT ADDS MORE PROPOSAL COSTS
- GENERAL TECHNOLOGY SOLICITATION TOO BROAD (SHOTGUN APPROACH TO TECHNOLOGY DEVELOPMENT)

# REVISED APPROACH

~~6-4-97~~

~~IN-STEP 88 WORKSHOP~~

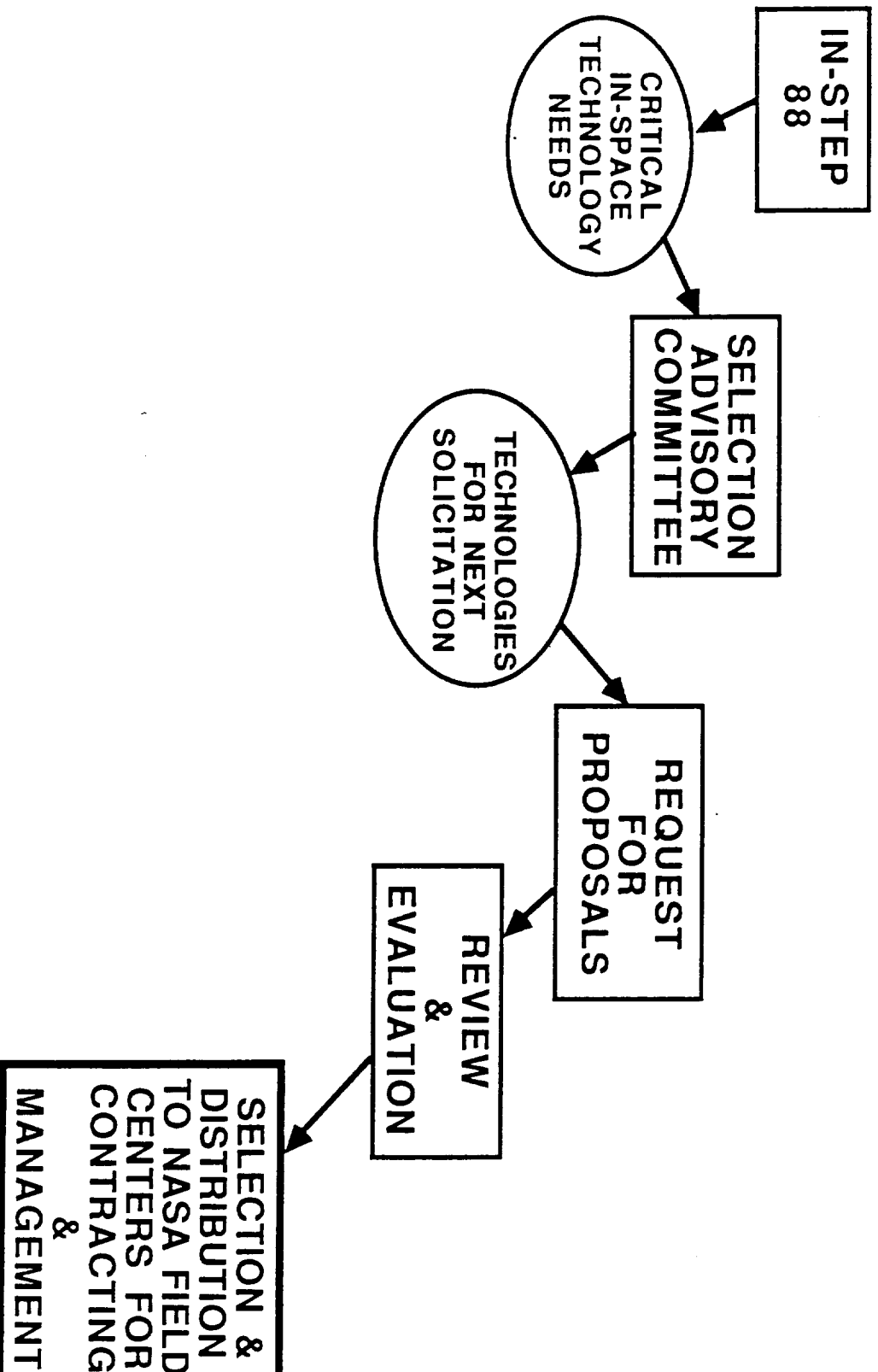
- DEFINE & PRIORITIZE CRITICAL SPACE TECHNOLOGY DEVELOPMENT REQUIREMENTS FOR FUTURE SPACE MISSIONS
- USE PRIORITIZED LISTING TO FOCUS FUTURE TECHNOLOGY DEVELOPMENT & IN-SPACE FLIGHT TECHNOLOGY EXPERIMENTS
- FUTURE SOLICITATIONS FOR DEFINITION OF FOCUSED IN-SPACE FLIGHT TECHNOLOGY EXPERIMENTS
- DOWN-SELECT BETWEEN COMPETING EXPERIMENTS FOR CONCEPTUAL DESIGN PHASE & FLIGHT HARDWARE DEVELOPMENT PHASE



# SOLICITATION PROCESS

~~0-4-31~~

~~IN-STEP 88 WORKSHOP~~



# SUMMARY

88

- LONG & SUCCESSFUL HISTORY IN THE CONDUCT OF SPACE FLIGHT TECHNOLOGY EXPERIMENTS
- PROGRAM IS BEING EXPANDED TO EMPHASIZE THE DEVELOPMENT OF ADVANCED SPACE FLIGHT TECHNOLOGIES
- OAST PLANS TO PROVIDE ACCESS TO SPACE FOR THE AEROSPACE TECHNOLOGY COMMUNITY (NASA, DOD, INDUSTRY & UNIVERSITIES)

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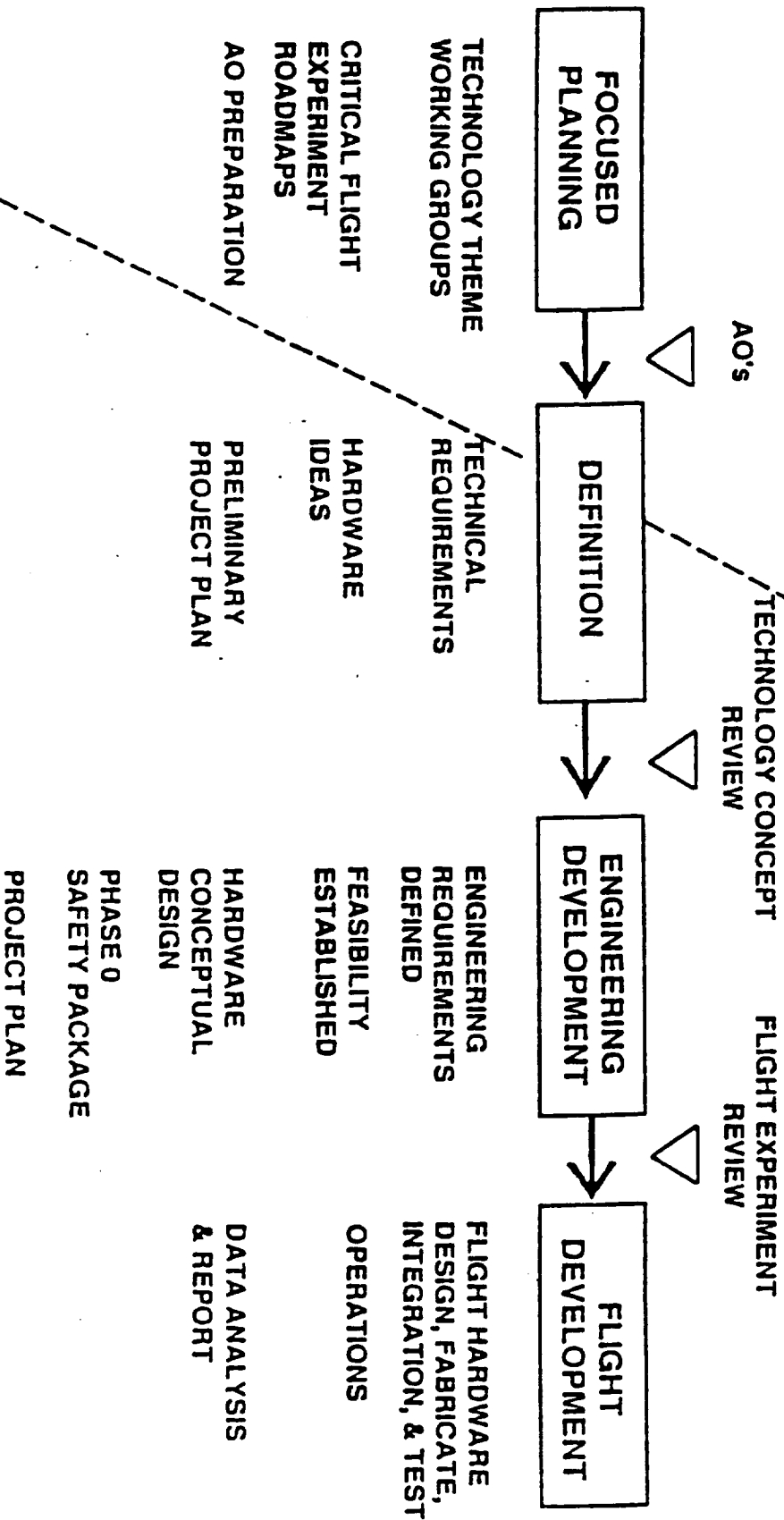
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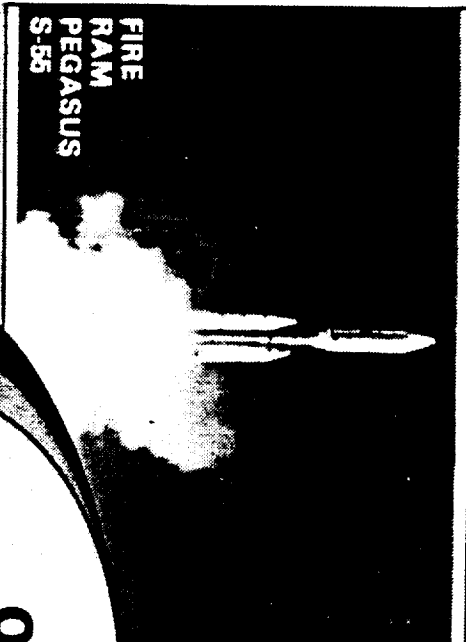
# OAST IN-SPACE TECHNOLOGY PROGRAM PHASES

## PROGRAM DEVELOPMENT

## PROJECT MANAGEMENT



# APOLLO

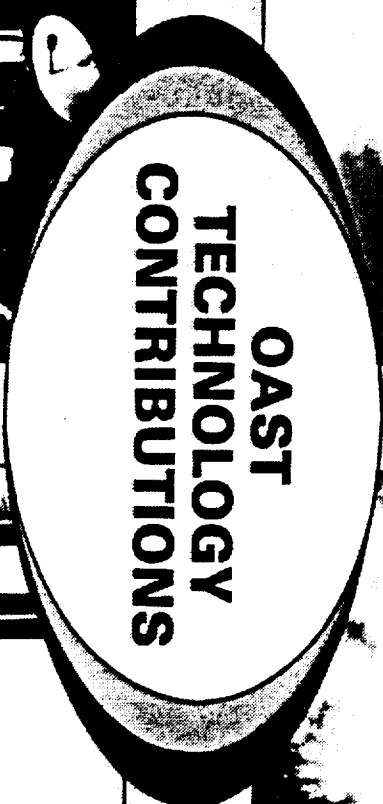


FIRE  
RAM  
PEGASUS  
S-55

# SHUTTLE



M-2  
HL-10  
X-24B

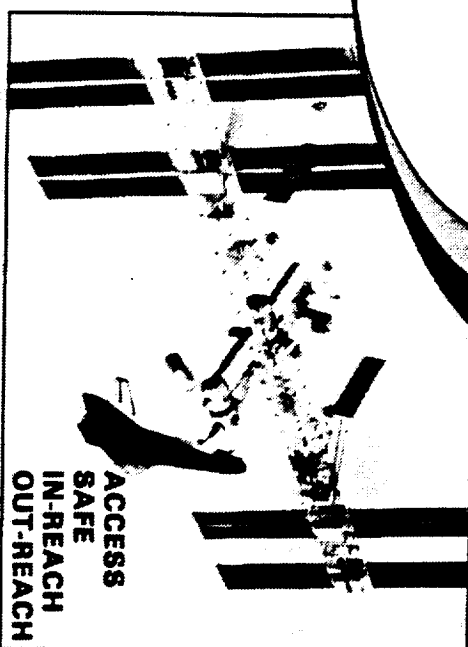


# VIKING



VAET  
PERP

# GROWTH SPACE STATION



ACCESS  
SAFE  
IN-REACH  
OUT-REACH

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# **SPACE STATION FREEDOM USER/PAYLOAD INTEGRATION AND ACCOMMODATIONS**

## **PRESENTATION TO THE**

### **NASA OAST IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP**

**DECEMBER 6, 1988**

**ALAN C. HOLT**

**DEPUTY DIRECTOR (ACT), USER  
INTEGRATION DIVISION**

**UTILIZATION & OPERATIONS GROUP**

**NASA SPACE STATION FREEDOM  
PROGRAM OFFICE**

**RESTON, VIRGINIA**

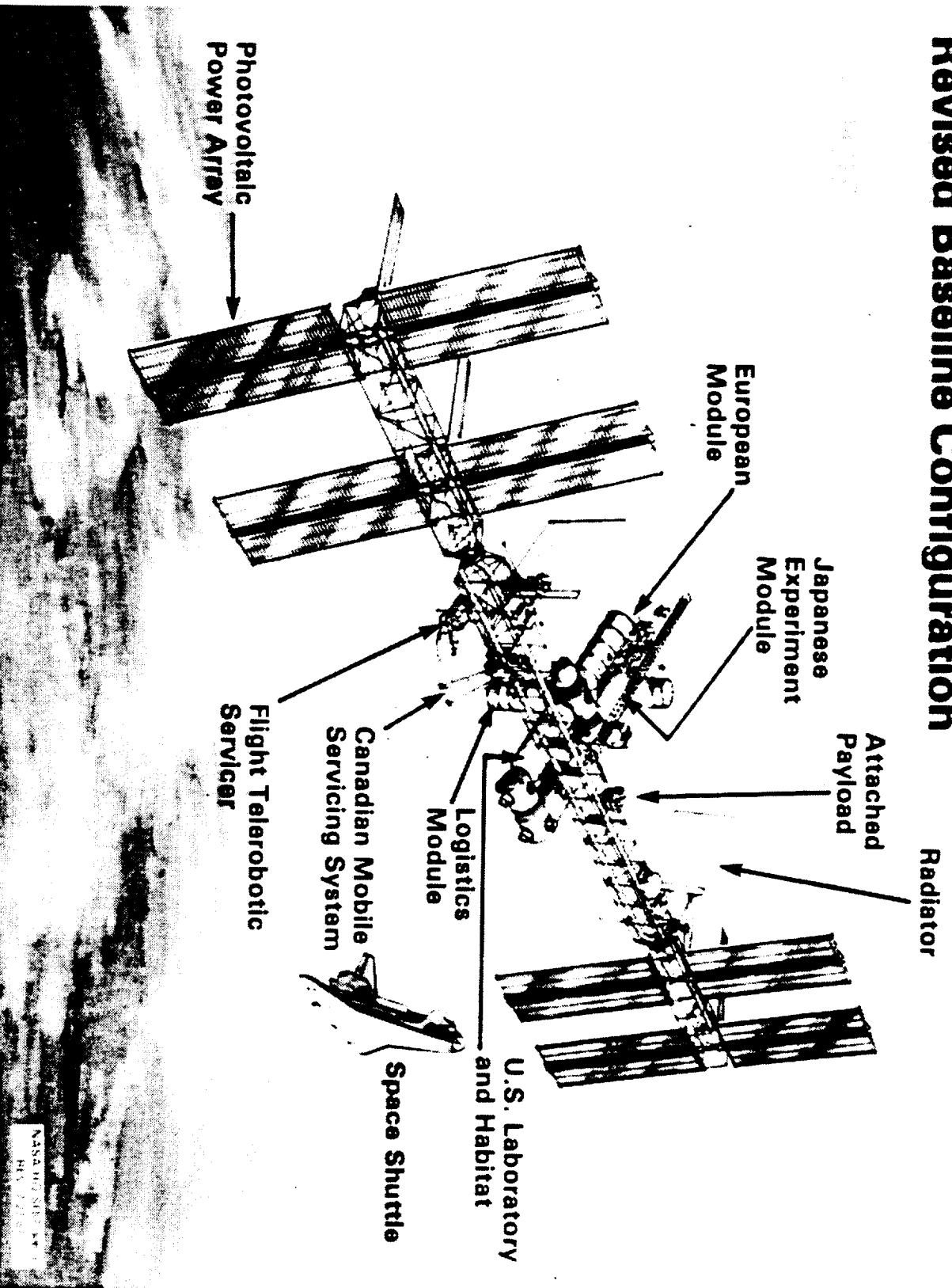
## **SPACE STATION FREEDOM TECHNOLOGY PAYLOADS**

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- **CRITICAL TO THE SUCCESS OF THE SPACE STATION GROWTH OR DEVELOPMENT AND FUTURE SPACE PROJECTS AND MISSIONS.**
- **EFFECTIVE WAY OF AUGMENTING SPACE STATION PAYLOAD ACCOMMODATION CAPABILITIES - TEST AND CONVERSION TO OPERATIONAL USE.**
- **PROMOTE THE DEVELOPMENT OF TECHNOLOGICAL APPLICATIONS WHICH SUPPORT OTHER GOVERNMENT AND PRIVATE PROJECTS AND PRODUCTS.**
- **PROVIDES NEW EDUCATIONAL OPPORTUNITIES FOR NEW GENERATIONS OF SCIENTISTS, ENGINEERS, AND OTHER PROFESSIONS.**



# Revised Baseline Configuration

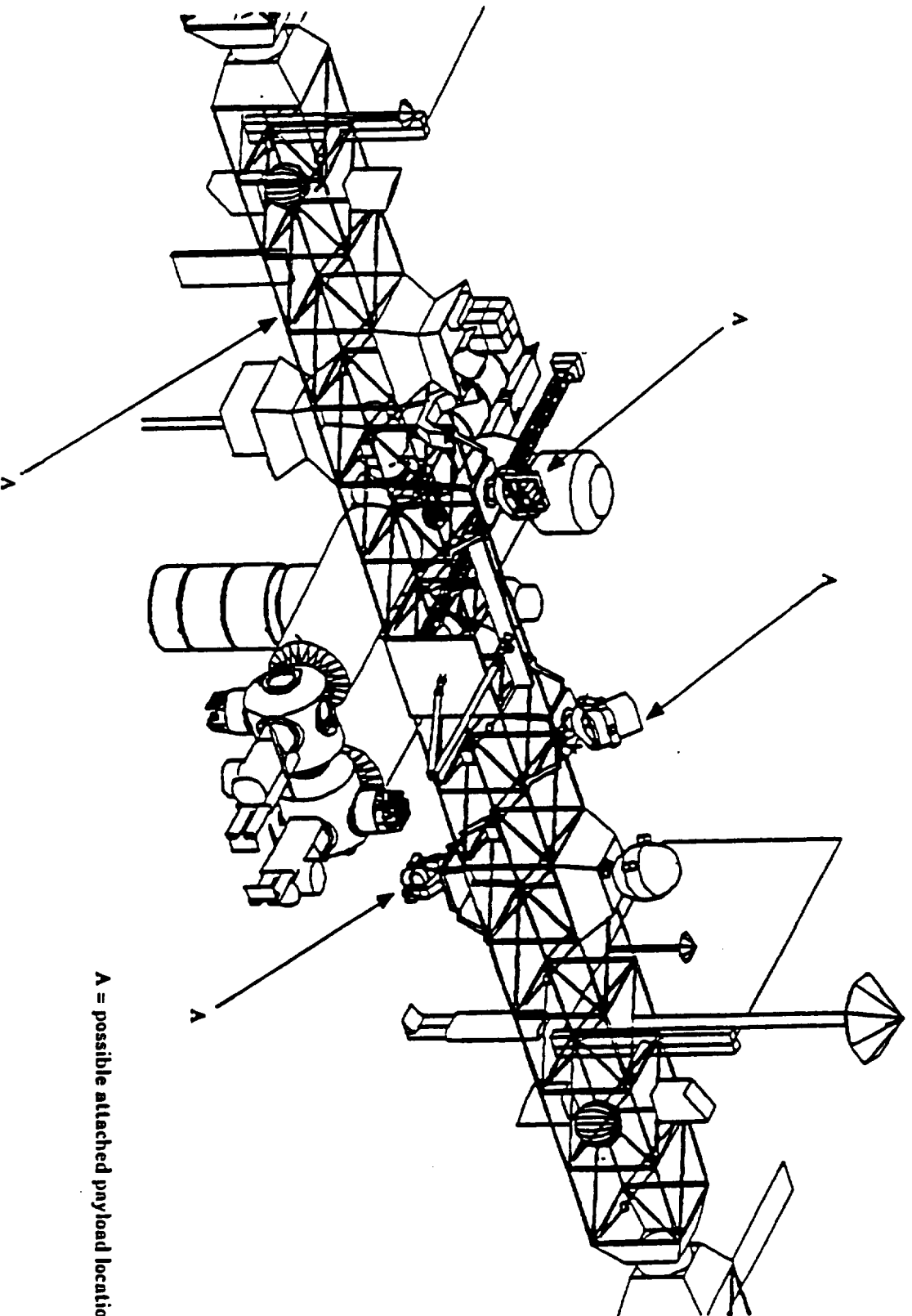


# **SPACE STATION FREEDOM TECHNOLOGY PAYLOAD ACCOMMODATION**

---

- **MATERIALS R&D**
- **ADVANCED RADIATOR AND POWER SYSTEM**
- **ADVANCED PROPULSION SYSTEMS**
- **TECHNOLOGY PAYLOADS WITH STRONG MAGNETIC FIELDS**
- **LASER SYSTEMS - OPTICAL COMMUNICATION**
- **ELECTRON BEAMS, WAVE GENERATION, ETC.**
- **INTERNAL TECHNOLOGY PAYLOADS - RADIATION, SEU**
- **ADVANCED ECLS SUBSYSTEMS**

# Potential Attached Payload Locations



A = possible attached payload locations

NOTE: Could utilize more than one truss-cube surface but utility port provided resources would have to be shared.

SSU-8814316  
1582 12/04/88 M/JF

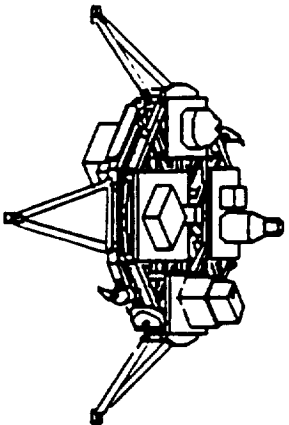
# **MANNEED BASE ATTACHED PAYLOAD ACCOMMODATIONS**

## **PAYLOAD CLASSIFICATION**

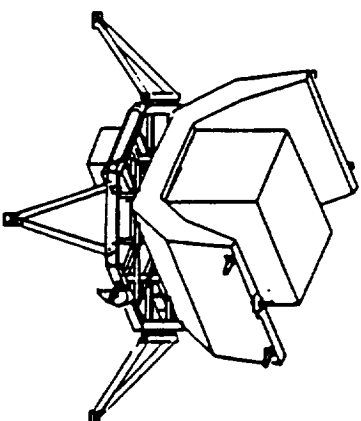
<b>CLASS</b>	<b>PAYLOAD FEATURES</b>
<b>MAJOR</b>	<ul style="list-style-type: none"> <li>• <b>LARGE</b></li> <li>• <b>REQUIRES MAJOR APAC RESOURCES</b></li> <li>• <b>ACTIVE THERMAL COOLING</b></li> <li>• <b>SOME NEED PPS FOR POINTING</b></li> <li>• <b>LONG STAY</b></li> </ul>
<b>SMALL AND/OR RAPID RESPONSE</b>	<ul style="list-style-type: none"> <li>• <b>SMALL</b></li> <li>• <b>NO ACTIVE THERMAL COOLING</b></li> <li>• <b>MODEST POWER/DATA RESOURCES</b></li> <li>• <b>VARIETY OF FIELDS OF VIEW</b></li> <li>• <b>SET ASIDE RESOURCES</b></li> </ul>
<b>DISTRIBUTED SENSOR</b>	<ul style="list-style-type: none"> <li>• <b>CAN BE VERY SMALL IN SIZE (LIKE ACCELEROMETER)</b></li> <li>• <b>NON-STANDARD LOCATIONS</b></li> <li>• <b>MODEST POWER/DATA RESOURCES</b></li> <li>• <b>CAN BE ANALYTICALLY INTENSIVE</b></li> <li>• <b>CAN HAVE UNIQUE PACKAGING</b></li> </ul>



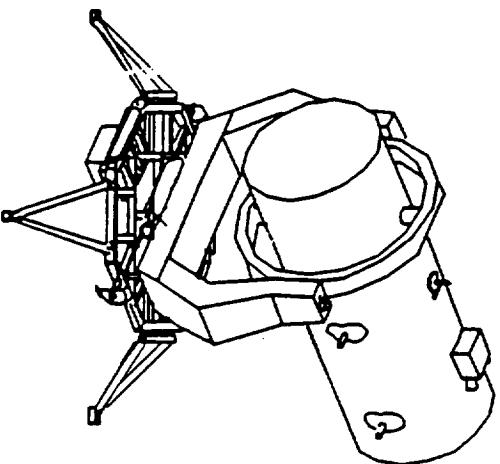
# APAE TYPICAL CONFIGURATIONS



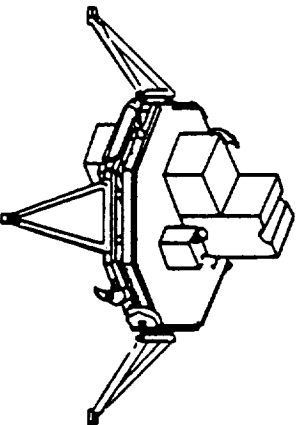
**MULTIPLE PAYLOADS**



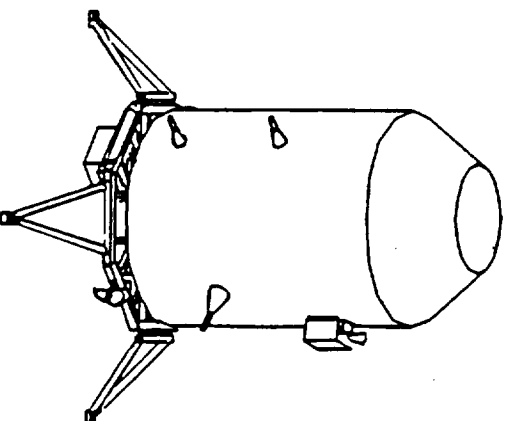
**PALLET MOUNTED PAYLOAD**



**PAYLOAD AND PAYLOAD  
POINTING SYSTEM**



**SINGLE PAYLOAD**



**LARGE PAYLOAD**

## MANNED BASE ATTACHED PAYLOAD ACCOMMODATIONS

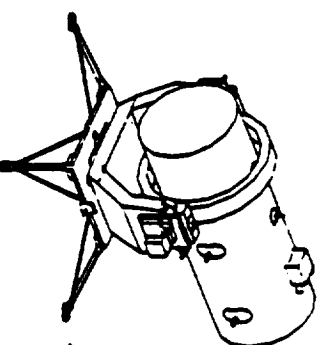
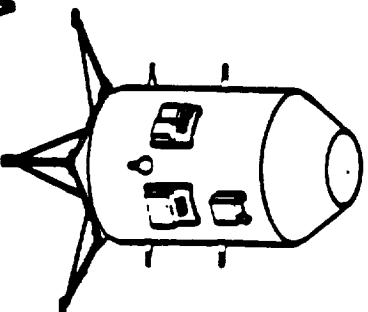
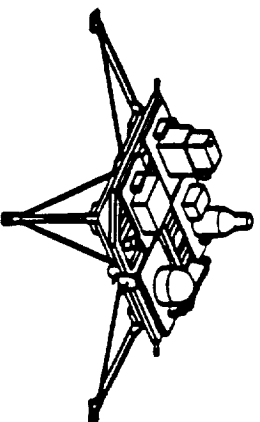
### APAE DESIGN CAPABILITY

#### DESIGNED FOR:

**MULTIPLE PAYLOADS**

**MAJOR**

**POINTING  
PAYLOADS**

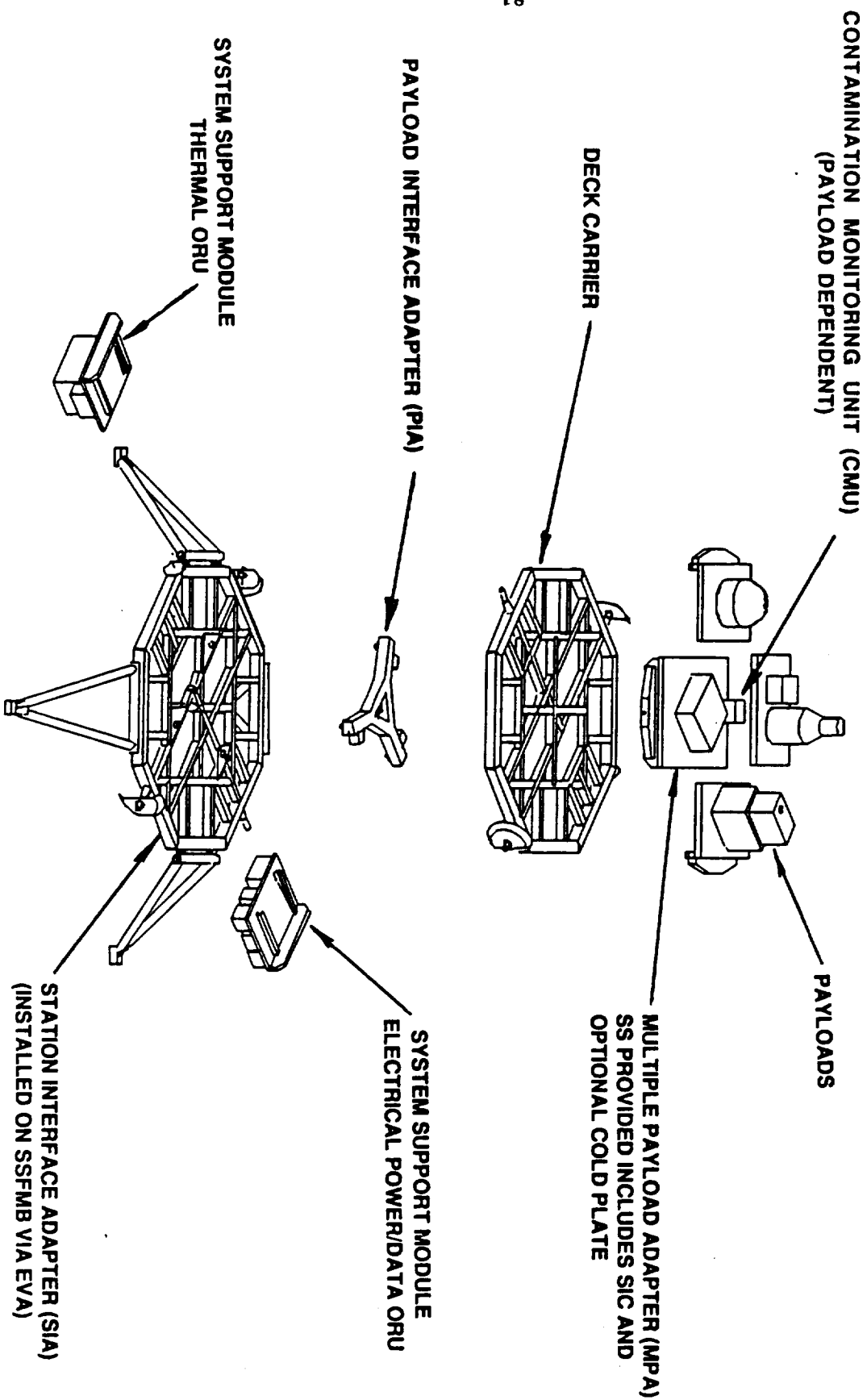


**4 COMPATIBLE PAYLOADS VIA  
MULTIPLE PAYLOAD ADAPTERS (MPAs)**

- APAE DESIGNED TO SUPPORT UP TO 25,000 LB PAYLOAD
- PROVIDES: 10kw POWER  
50 MBPS DATA RATE  
10 kw ACTIVE COOLING } **PAYLOAD(S)**
- STRUCTURAL SUPPORT FOR POINTING CAPABILITY (60 ARC SEC  
ACCURACY) FOR 6000 kg PAYLOAD



# MULTIPLE PAYLOAD/DECK CARRIER CONFIGURATION

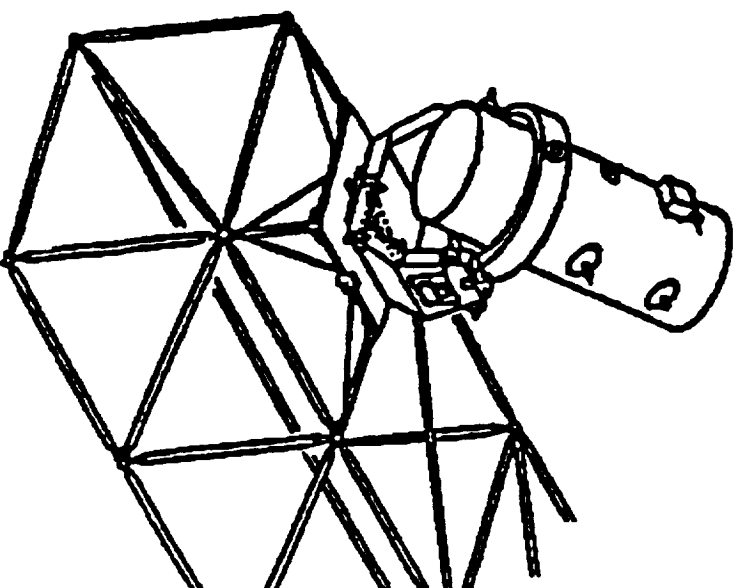


# PAYLOAD POINTING SYSTEM (PPS)

---

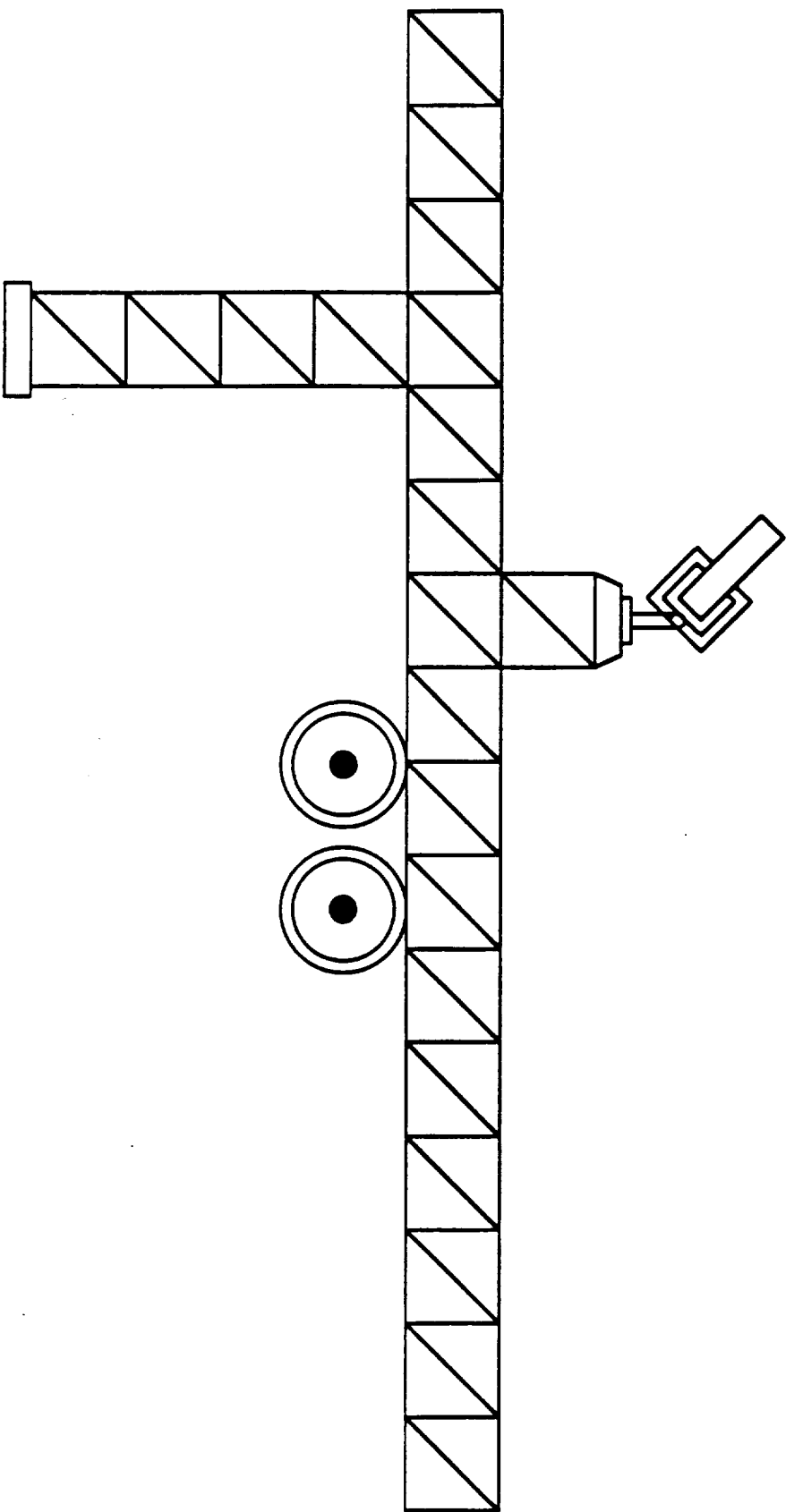
## PPS PAYLOAD ACCOMDATION CAPABILITIES

- 1 ARC MINUTE POINTING ACCURACY
- 30 ARC SECOND POINTING STABILITY  
(OVER 1800 SECS)
- 15 ARC SECOND/SECOND JITTER
- 3 AXES
- 5 KW OF POWER/ACTIVE COOLING
- 50 MEGABITS HIGH RATE DATA/IMAGERY
- 6000 KG PAYLOAD - 3 METERS WIDE,  
C.G. TO BASE 2.5 METERS
- ACCEPTS PAYLOAD SENSOR INPUT FOR POINTING

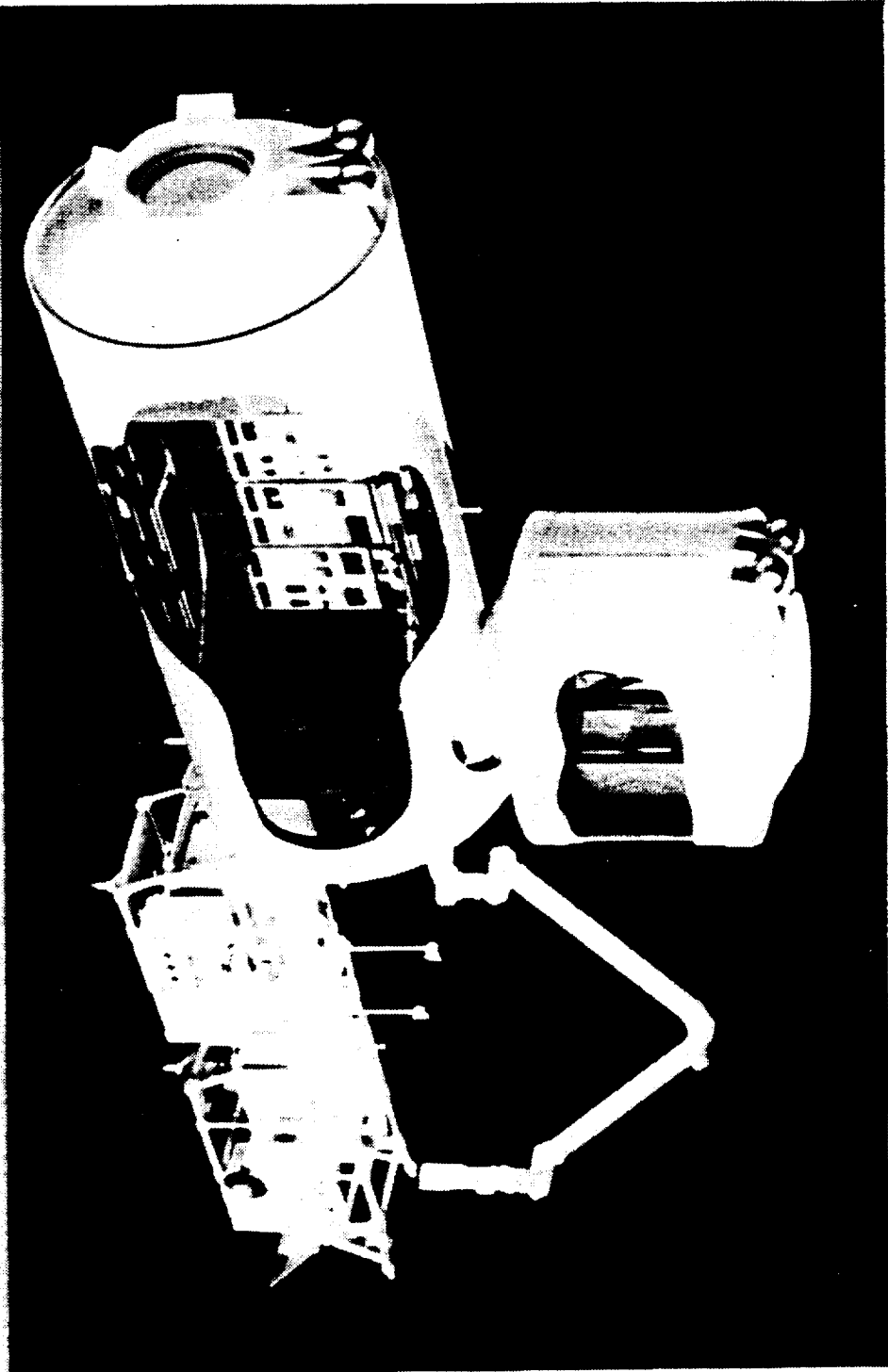




# CAPABILITY TO ADD TRUSS STRUCTURE TO ENHANCE ATTACHED PAYLOAD VIEWING AND CLEARANCE



# JAPANESE EXPERIMENT MODULE

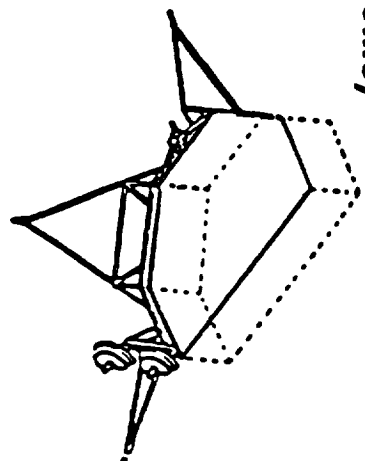


# SMALL AND RAPID RESPONSE PAYLOADS

## EXTERNAL SARR PAYLOAD ENVELOPE & PROPOSED CONSTRAINTS

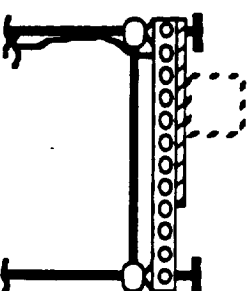
- TRUNNION/KEEL (T/K) SARR PAYLOAD:

FIT INTO 4M X 1.25M X 2M ENVELOPE (MAX VOL <10M3)  
≤ 900 KG  
≤ 900 WATTS  
≤ 0.3 MBPS UPLINK/2.0 MBPS DOWNLINK  
≤ 100 MBYTES DATA STORAGE/ORBIT  
CAN ACCOMMODATE MORE THAN ONE PAYLOAD  
RMS GRAPPLE FIXTURE (ON T/K CARRIER)



- GENERIC (GEN) SARR PAYLOAD:

FIT INTO 1.25 M X 1.25 M X 1.25 M ENVELOPE (MAX VOL ≤ 2 M3)  
≤ 300 KG  
≤ 300 WATTS  
≤ 0.3 MBPS UPLINK/2.0 MBPS DOWNLINK  
≤ 100 MBYTES DATA STORAGE/ORBIT  
ORU COMPATIBLE I/F (ORU TOOL)



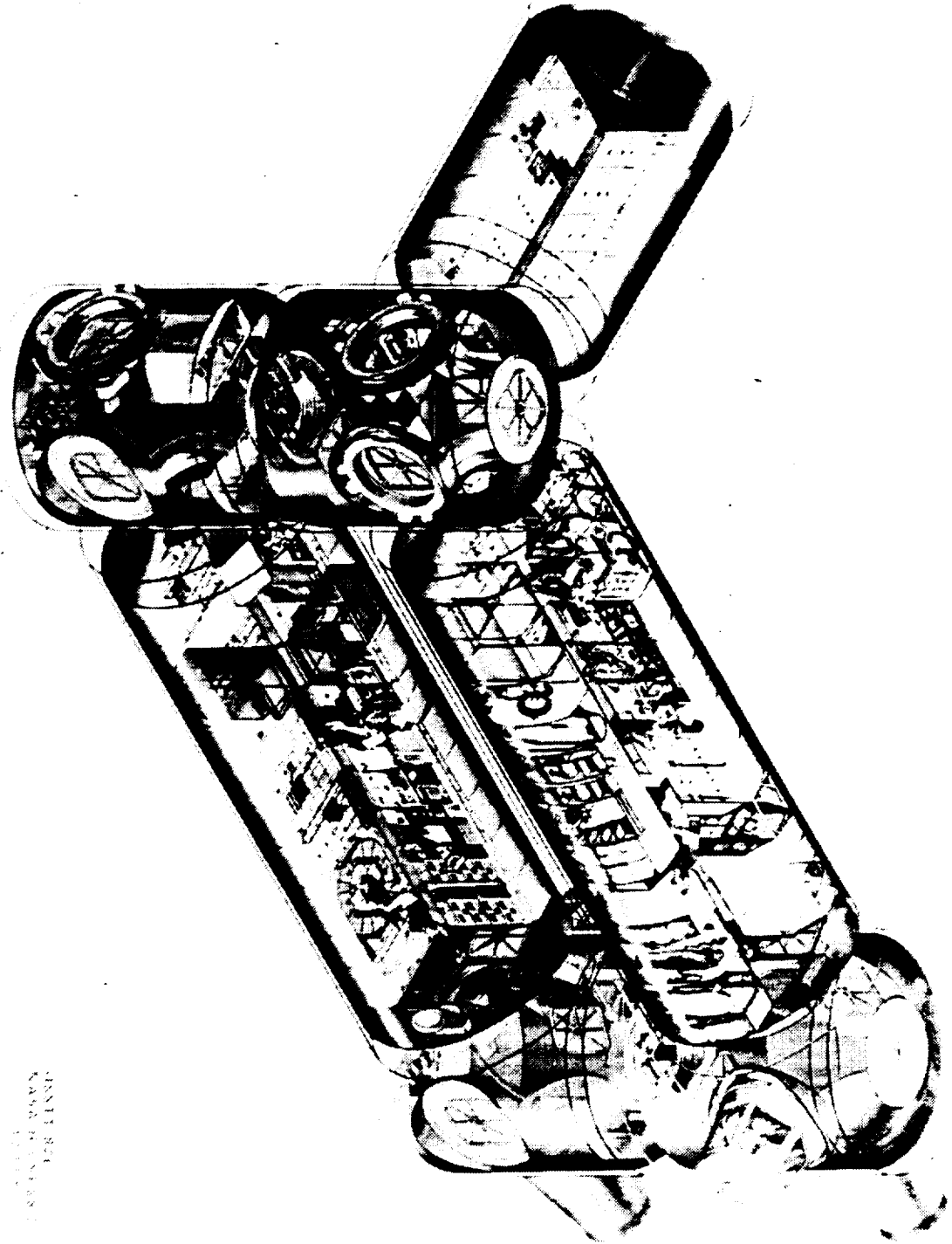
# SMALL AND RAPID RESPONSE PAYLOADS

## INTERFACE COMPARISON CHART FOR RELATIVELY SMALL ATTACHED PAYLOADS\* ON TRUSS AND JEM EF (PROPOSED)

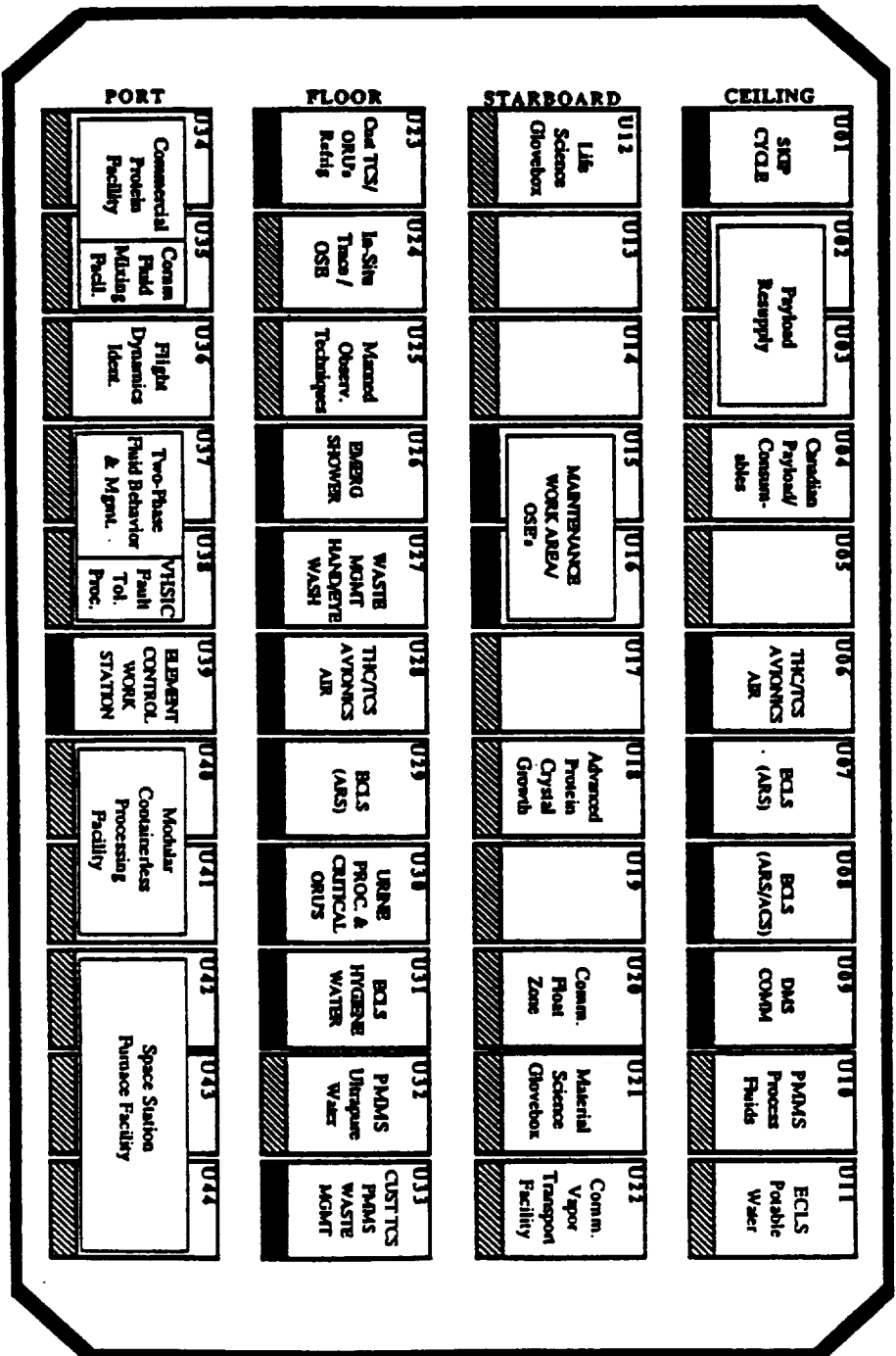
Interface or Physical Constraint	PAYLOAD		
	SAFR Trunnion Keel	SAFR Generic	JEM Exposed Facility
Weight	≤ 1980 lbs ≤ 900 kg	≤ 660 lbs ≤ 300 kg	typically 1100 lbs or 500 kg
Volume Limitations Physical Dimensions	~ 10m <sup>3</sup> 1.25m x 2.0m x 4.0m	~ 2m <sup>3</sup> 1.25m x 1.25m x 1.25m	~ 2m <sup>3</sup> 0.8m x 1.0m x 1.85m (0.8m x 1.0m footprint)
Thermal Cooling	only passive	only passive	≤ 6kW active cooling
Power Constraint	≤1.5kW	≤0.3kW	≤6.0kW
Data Rates Downlink Uplink	2.0 Mbps 0.3 Mbps	1.4 Mbps 0.3 Mbps	4 Mbps 4 Mbps
Access to Pressurized Module	None	None	Possible thru JEM Airlock
Pointing Capability Provided	None	None	None

\* These do not require an APAE

# U.S. SPACE STATION PRESSURIZED MODULES



# TRIAL PAYLOAD MANIFEST, U.S. LABORATORY MODULE: AFTER OUTFITTING FLIGHT OF-1



# COMMAND/CONTROL WORKSTATION DESIGN CONCEPT

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## DMS Fixed MPAC Components

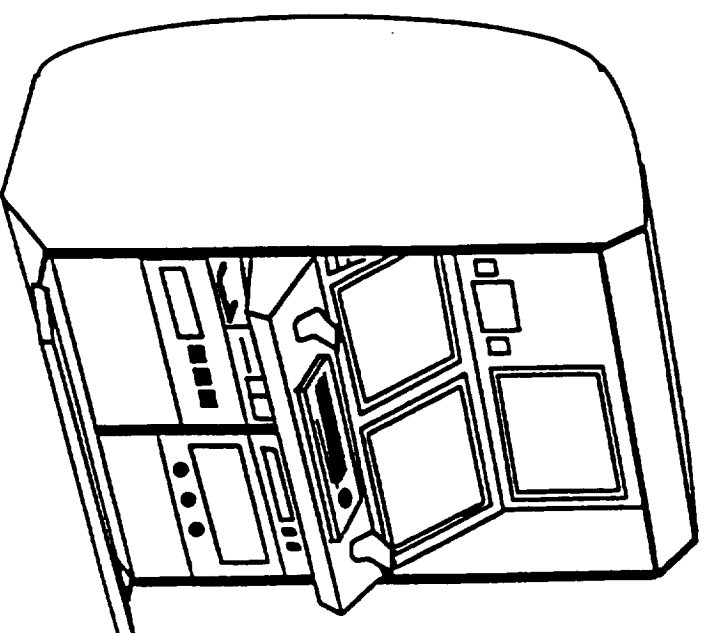
- Three 15" color CRTs
- QWERTY keyboard
- Trackball
- Hand controllers
- Processor
- Safety-critical D&C
- Hard-copy printer/plotter

## Other Components

- Video recorders
- Audio recorders
- Lighting
- Crew restraints

## Functions

- Subsystem management, customer support, proximity operations, telerobotic (MSC, FTS) control, external operations support

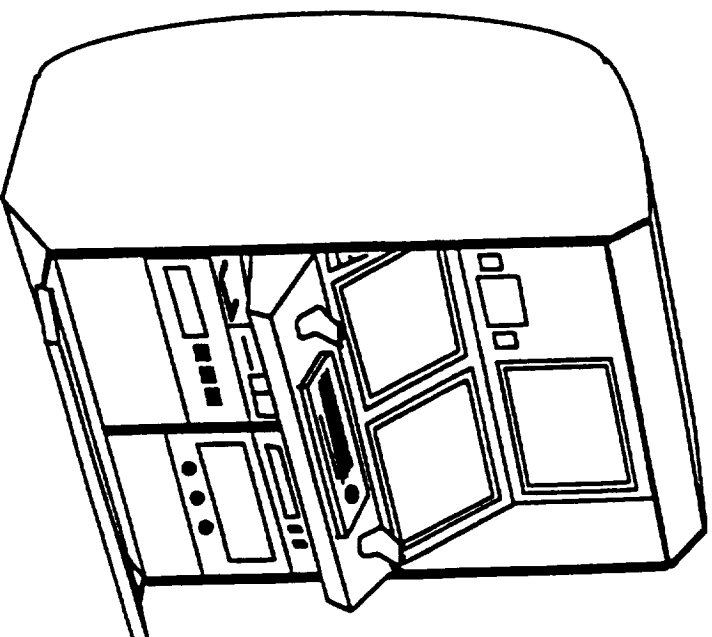


# COMMAND/CONTROL WORKSTATION DESIGN CONCEPT

---

## Key MPAC Requirements

- Alphanumerics
- Graphics
- Animation
- Integrated Video, Graphics, Text
- Color Displays
- Windowing
- Voice Input
- Voice Output
- 3D Graphics
- Run the DMS USE Software





**NASA** National Aeronautics and  
Space Administration

S88-44313

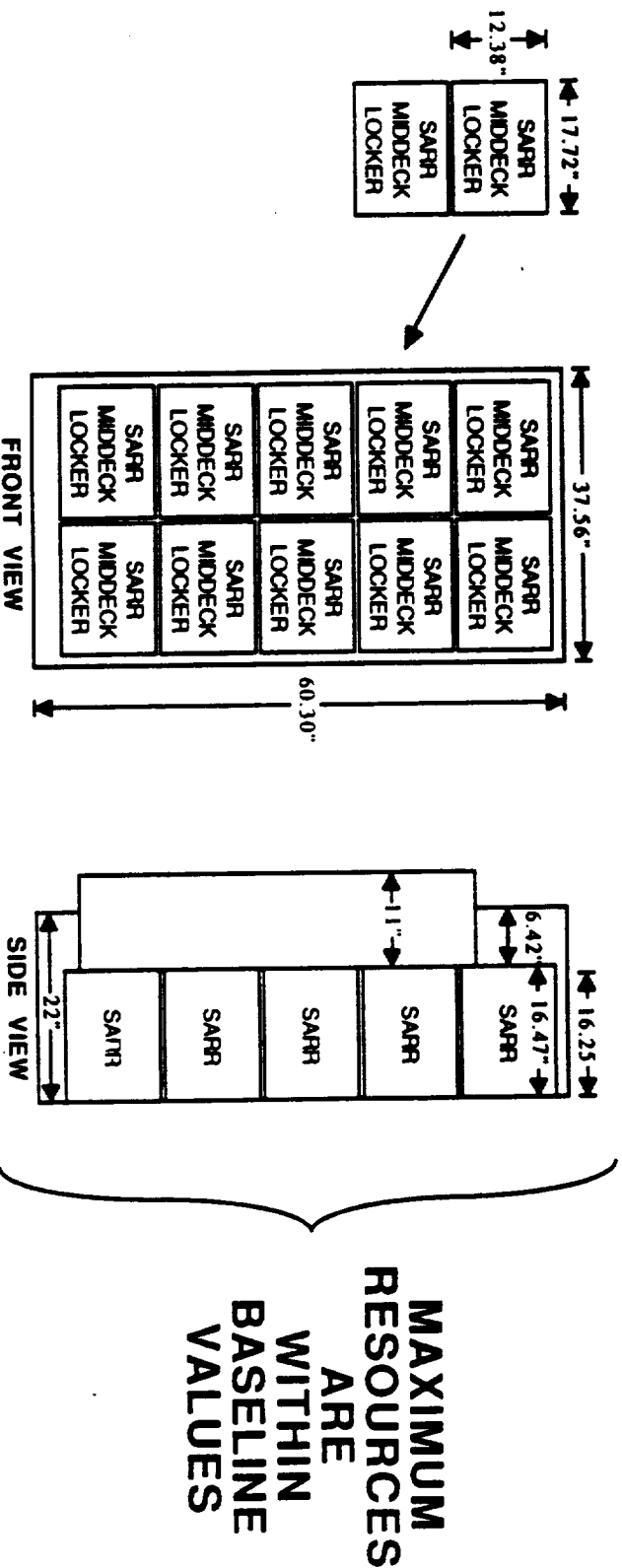
Lyndon B. Johnson Space Center  
Houston, Texas 77058



# INTERNAL SARR PAYLOAD REQUIREMENTS

- LOCATION REQUIREMENTS:  
DEDICATED STANDARD DOUBLE RACK FOR UP TO 10 INTERNAL SARR PAYLOADS. RACK SHALL BE CAPABLE OF BEING RECONFIGURED ON ORBIT TO SUPPORT STANDARD SARR PAYLOADS.

- RESOURCE PROVISIONS FOR DEDICATED STANDARD DOUBLE RACK:

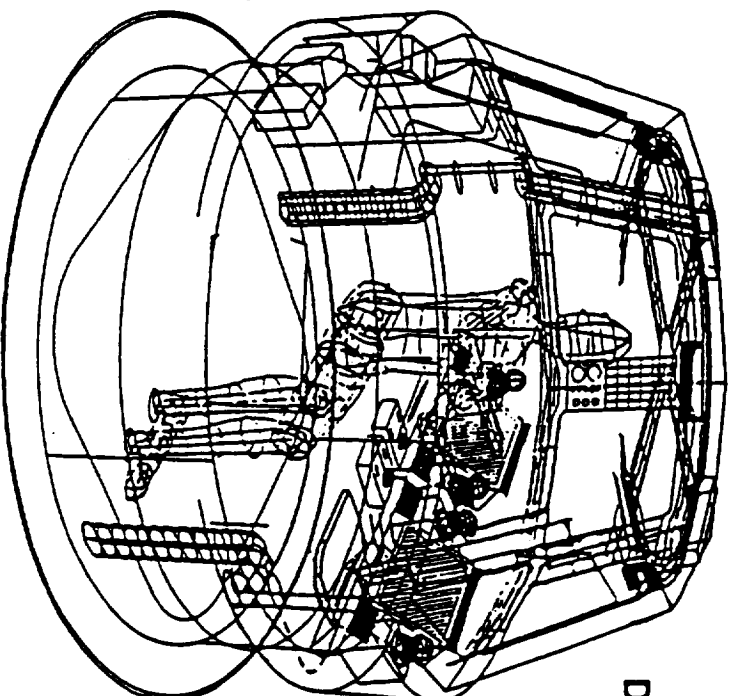


# CUPOLA WORKSTATION CONCEPT

## Key Cupola MPAC Reqt's

- Alphanumerics
- Graphics
- Animation
- Video
- Telerobotics Control
- OMV Piloting
- MSC Control
- Run the DMS USE Software

36



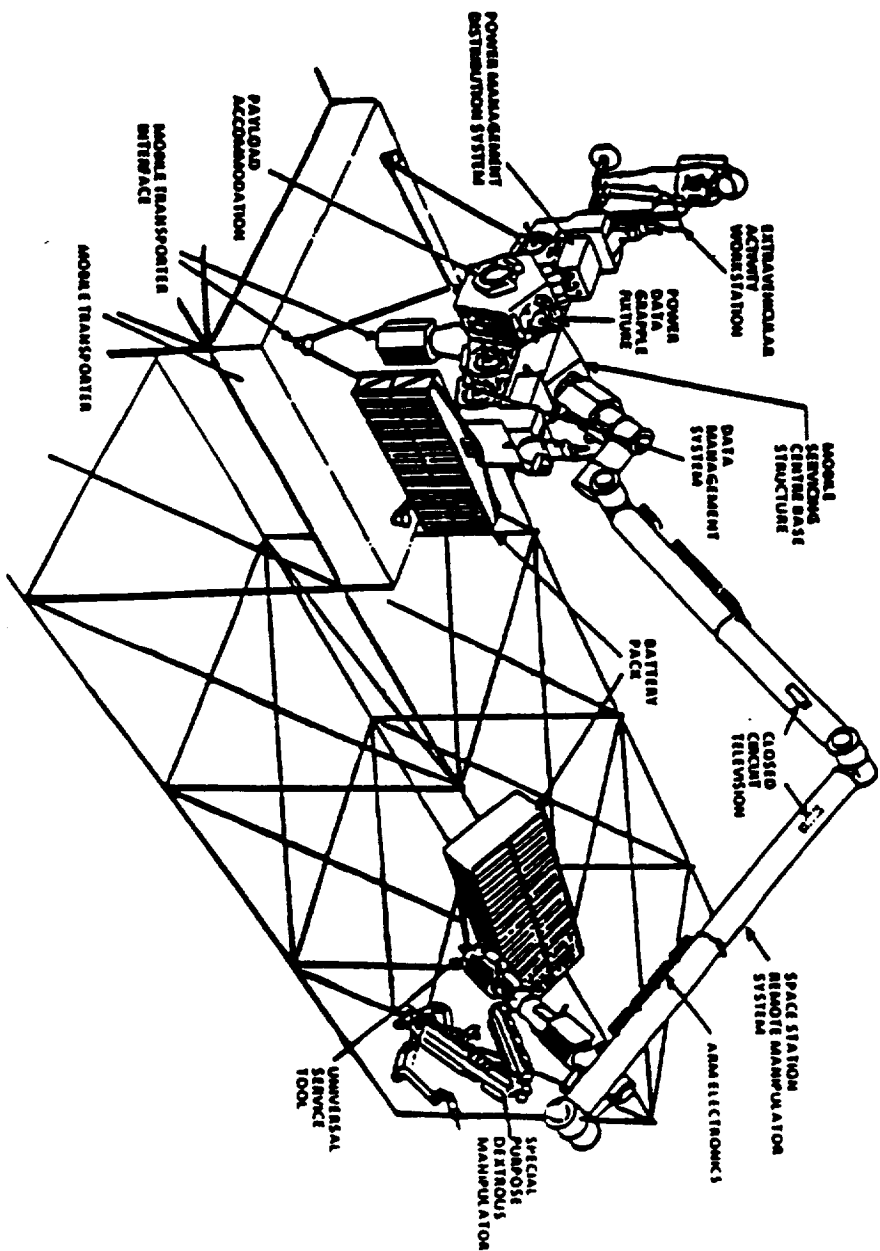
## DMS Cupola MPAC Component

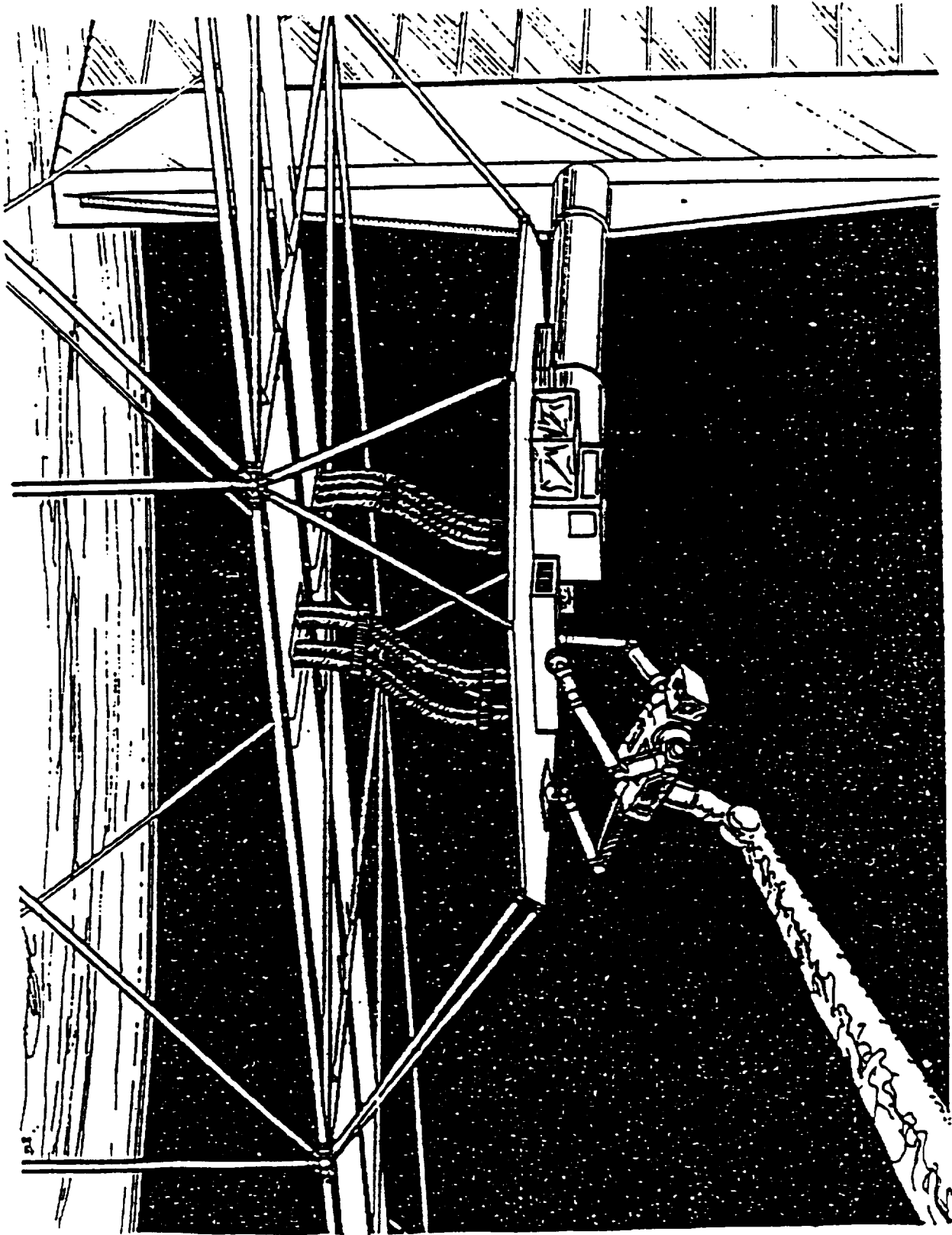
- Two 15" TFEL Displays
- Two QWERTY keyboards
- Two Trackballs
- Hand controllers
- Processor

## Other Components

- Lighting
- Crew restraints

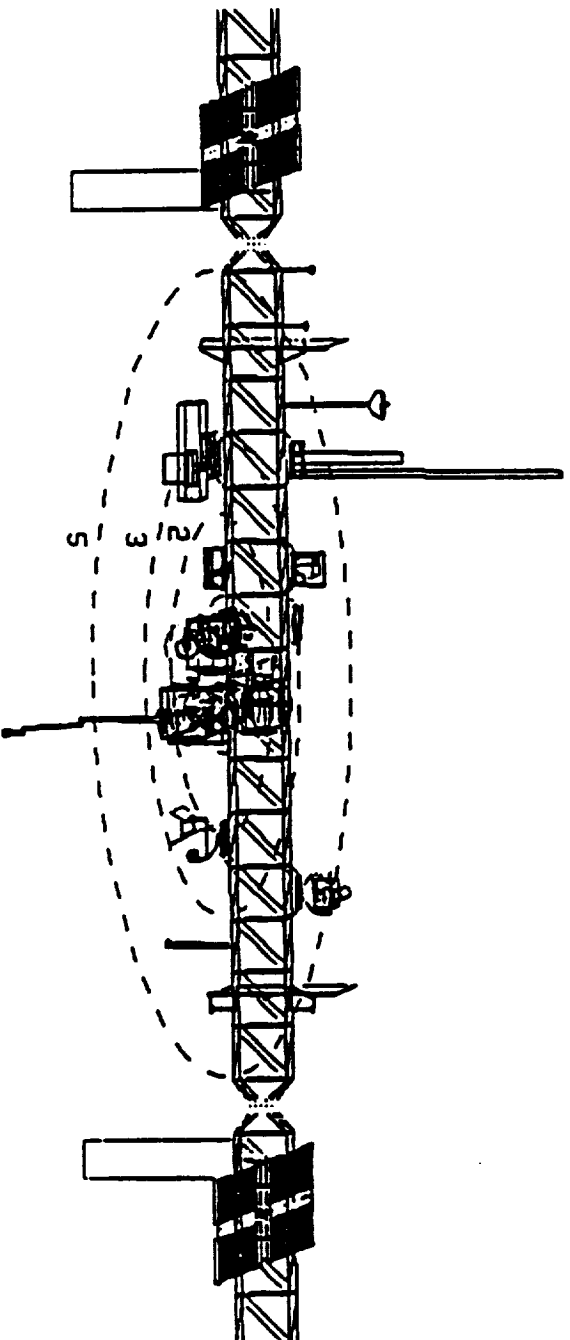
# MOBILE SERVICING CENTER



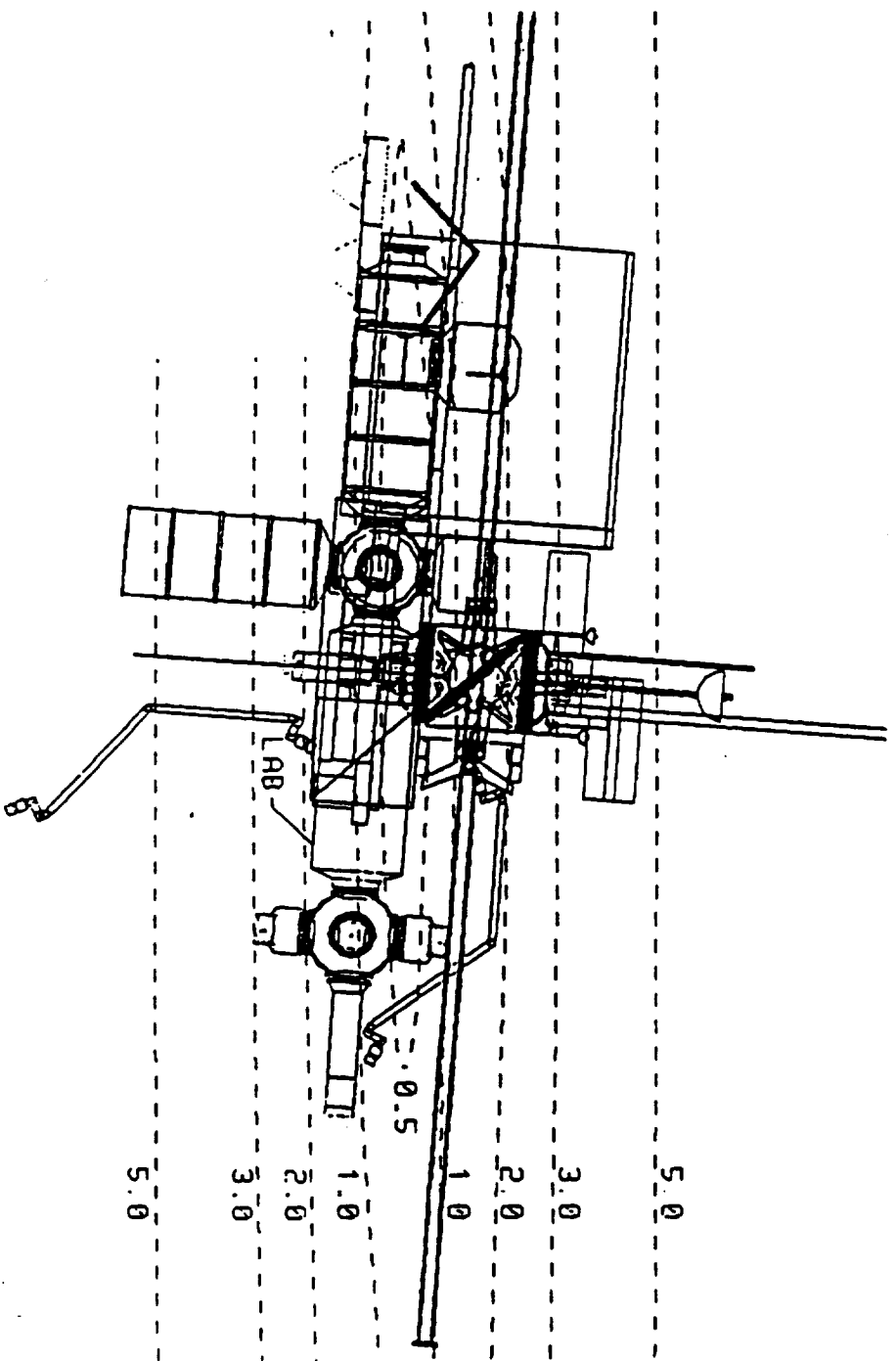


# Microgravity Quasi-Static Isogravity Contours ( $\times 10^{-6}$ G) (June, 1999, Altitude 230 n. miles) Front View

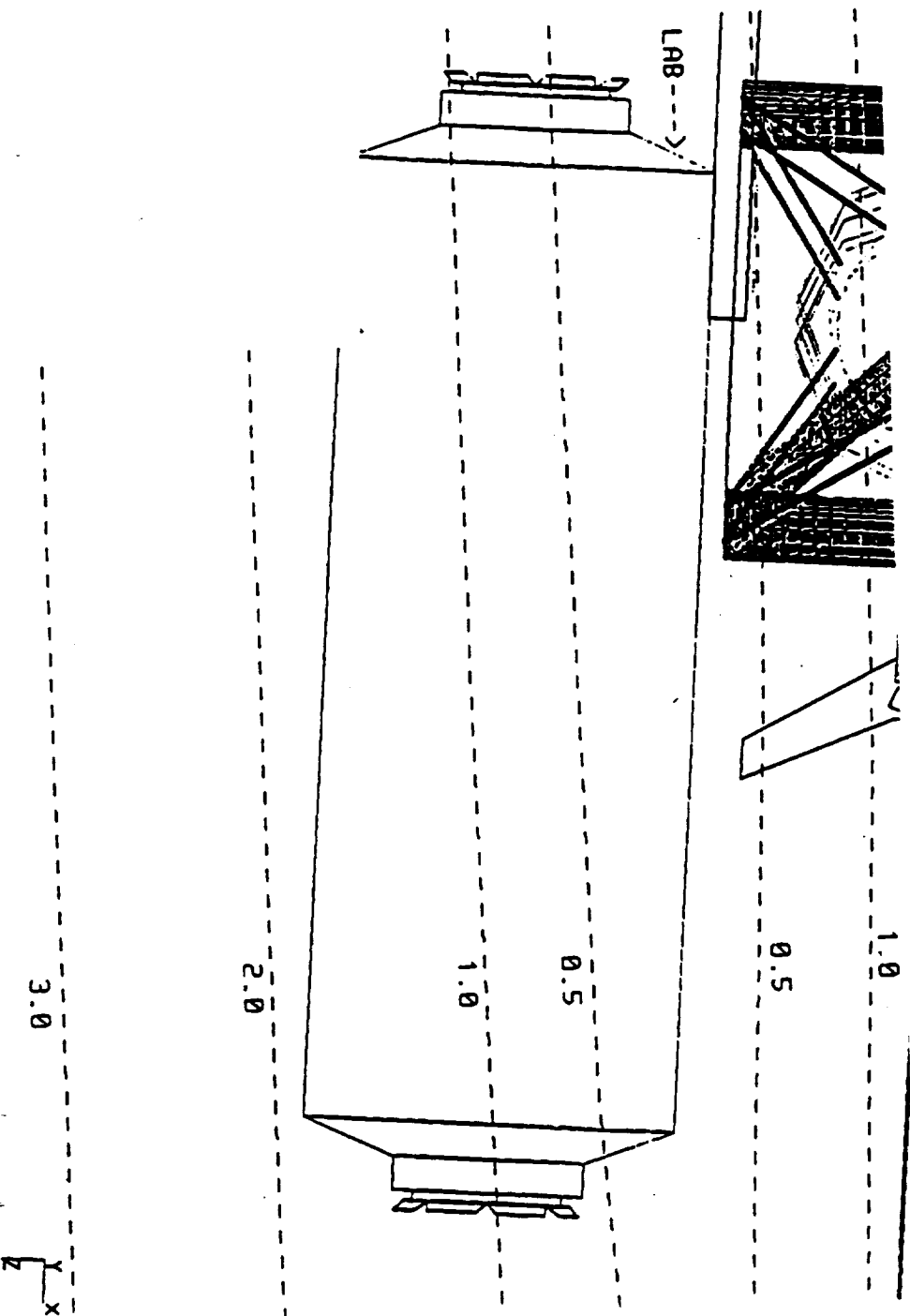
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# Microgravity Quasi-Static Isogravity Contours ( $\times 10^{-6} G$ ) (June, 1999, Altitude 230 n. miles) Side View



**Microgravity Quasi-Static Isogravity Contours ( $\times 10^{-6} G$ )**  
**(June, 1999, Altitude 230 n. miles)**  
**Close-up of U.S. Laboratory**





# **SPACE STATION ELECTROMAGNETIC COMPATIBILITY AND ENVIRONMENTAL INTERACTIONS STUDY**

---

## **NATURAL ENVIRONMENTS**

- NEUTRAL
- PARTICULATE
- RADIATION
- MAGNETIC FIELD
- PLASMA
- EM RADIATION

## **ENVIRONMENT PERTURBATIONS**

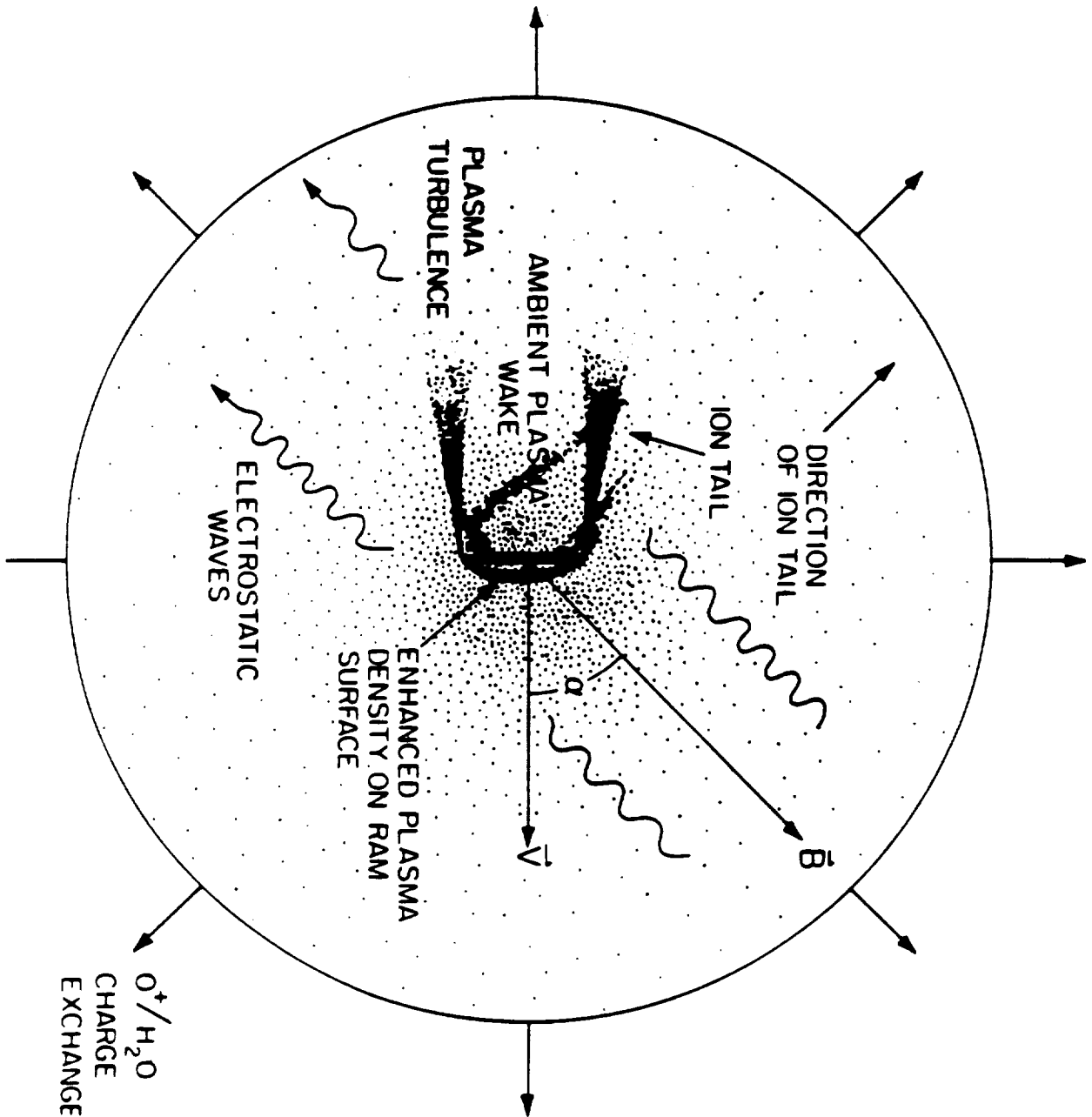
- THRUSTER FIRINGS
- VENTS AND OUTGASSING
- INDUCED CURRENTS
- COUPLING OF EM WAVES
- PLASMA BEAMS
- PARTICULATES
- RAM/WAKE

## **ENVIRONMENT INDUCED PHENOMENA**

- CHARGING
- ESD
- EMI
- HIGH VOLTAGE SURFACES
- SURFACE CONTAMINATION
- LONG TERM DEGRADATION

# INDUCED ENVIRONMENT NEAR LARGE SURFACES (ANDERSON [1984])

PARAMETERS	RAM	WAKE	COMMENT	EFFECT
NEUTRAL DENSITY, Torr	$10^{-5}$	$10^{-7}$	MEASURED	HIGH VOLTAGE SHORTS, CONTAMINATION
PLASMA DENSITY, $\text{cm}^{-3}$	AS HIGH AS $5 \times 10^6$	AS LOW AS $10$	MEASURED	POWER LOSS, ARCING
PLASMA WAVES	20 Hz - 300 KHz (22V/m) <sup>2</sup> /MHz AT PEAK	LOW	MEASURED ELECTROSTATIC WAVES	EM BACKGROUND NOISE
ENERGETIC PARTICLES	MEAN ENERGY OF ELECTRONS: 10 - 100 eV FLUX: $\sim 10^8/\text{cm}^2 \text{ sec ster eV}$ MEAN ENERGY OF IONS: 10 - 30 eV	LOW	HIGHER FLUXES PREDICTED; LITTLE NUMERICAL DATA PUBLISHED	PLASMA WAKE, DIFFERENTIAL CHARGING
GLOW, PHOTONS ( $\text{cm}^3\text{s})^{-1}$	$10^7 - 10^8$	LOW	GLOWING LAYER IN RAM 10-20 cm THICK	OPTICAL (IR) CONTAMINATION





# **POTENTIAL ENVIRONMENTALLY ACTIVE PAYLOADS**

## **ASTROMAG (EARLY ATTACHED PAYLOAD CANDIDATE)**

- ENERGY STORED BY MAGNETIC FIELD: 10 MEGA JOULES
- MAXIMUM MAGNETIC FIELD INTENSITY: 70,000 GAUSS
- FIELD CONFIGURATION: QUADRUPOLE, DECREASES TO EARTH'S MAGNETIC FIELD INTENSITY AT 15 METER DISTANCE

## **SOLAR TERRESTRIAL OBSERVATORY: PLASMA PHYSICS GROUP (LATER ATTACHED PAYLOAD CANDIDATE)**

- ELECTRON BEAMS
- WAVE GENERATORS - GROWTH VERSION UP TO 50 KW POWER REQUIREMENT

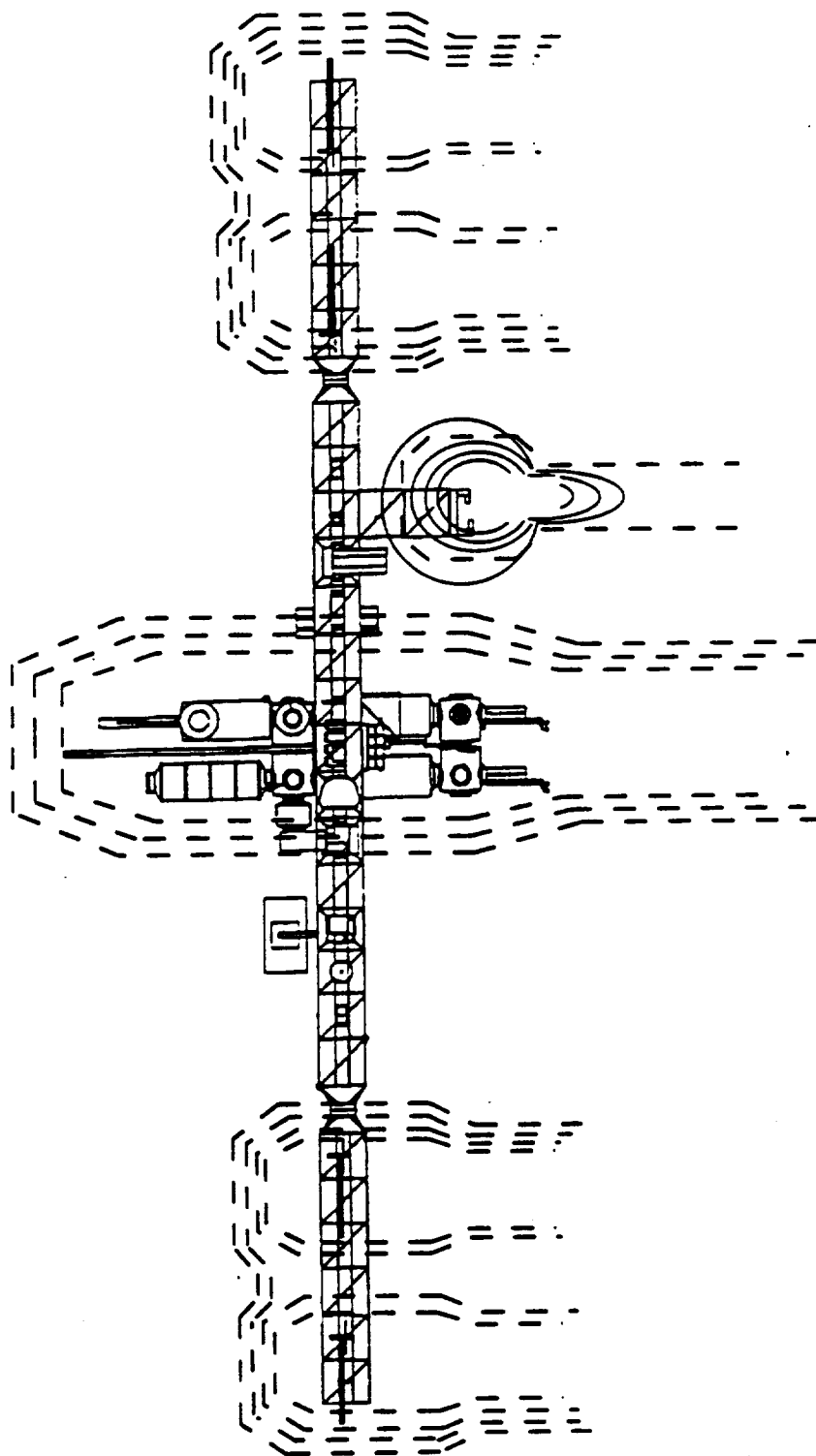
## **HIGH TEMPERATURE SUPERCONDUCTING MAGNETIC FIELD ENERGY STORAGE SYSTEM (CANDIDATE PAYLOAD ANTICIPATED)**

- HIGH MAGNETIC FIELD INTENSITIES

## **ADVANCED ELECTRIC AND ELECTROMAGNETIC PROPULSION SUBSYSTEM TECHNOLOGY TESTS (CANDIDATE PAYLOAD ANTICIPATED)**

- HIGH MAGNETIC FIELD AND ELECTRIC FIELD INTENSITIES

# INDUCED ENVIRONMENTAL EFFECTS OF ACTIVE TECHNOLOGY PAYLOADS - TOP VIEW



-- PLASMA ISO DENSITY CONTOUR  
— MAGNETIC FIELD ISO INTENSITY CONTOUR

SSJ-8814674  
1582 12/4/88 M/AK

# **SPACE STATION FREEDOM GROWTH CAPABILITIES / TECHNOLOGY PAYLOADS**

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## **SERVICING FACILITY**

- REPAIR AND CONDUCT RESUPPLY AND REFUELING OPERATIONS FOR FREE FLYERS AND CO-ORBITING PLATFORMS
- EXTENSIVE REPAIR WORK FOR ATTACHED PAYLOADS
- ASSEMBLY OF UPPER STAGES AND PAYLOADS

## **LARGE SPACE CONSTRUCTION FACILITY**

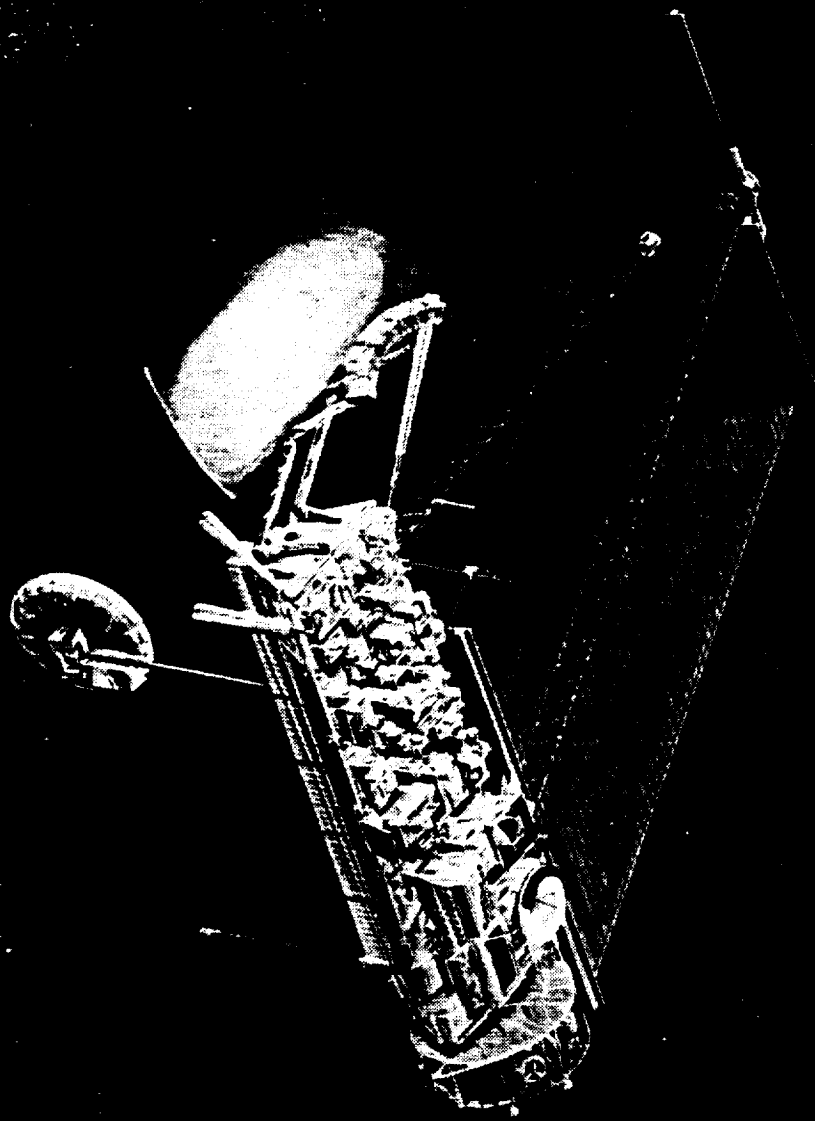
- LARGE CRANE FOR POSITIONING
- ADDITIONAL MOBILE ROBOTICS
- CAPABILITY TO ASSEMBLE LARGE ANTENNAS, PHASED-ARRAY OPTICAL SYSTEMS

## **CO-ORBITING PLATFORM, ADVANCED TECHNOLOGY TEST FACILITY**

- USER-SUPPLIED OR STATION-SUPPLIED PLATFORM TO CONDUCT PARTIAL OR FULLUP TESTS OF ADVANCED PROPULSION AND POWER SYSTEMS
- TESTING OF TECHNOLOGY INVOLVING HAZARDOUS MATERIALS OR OPERATIONS OR REQUIRING ORBITAL DYNAMICS NOT SUPPORTED BY THE STATION

SSU 8814298  
1582 11/29/88 M/JF

# SPACE STATION FREEDOM POLAR PLATFORM



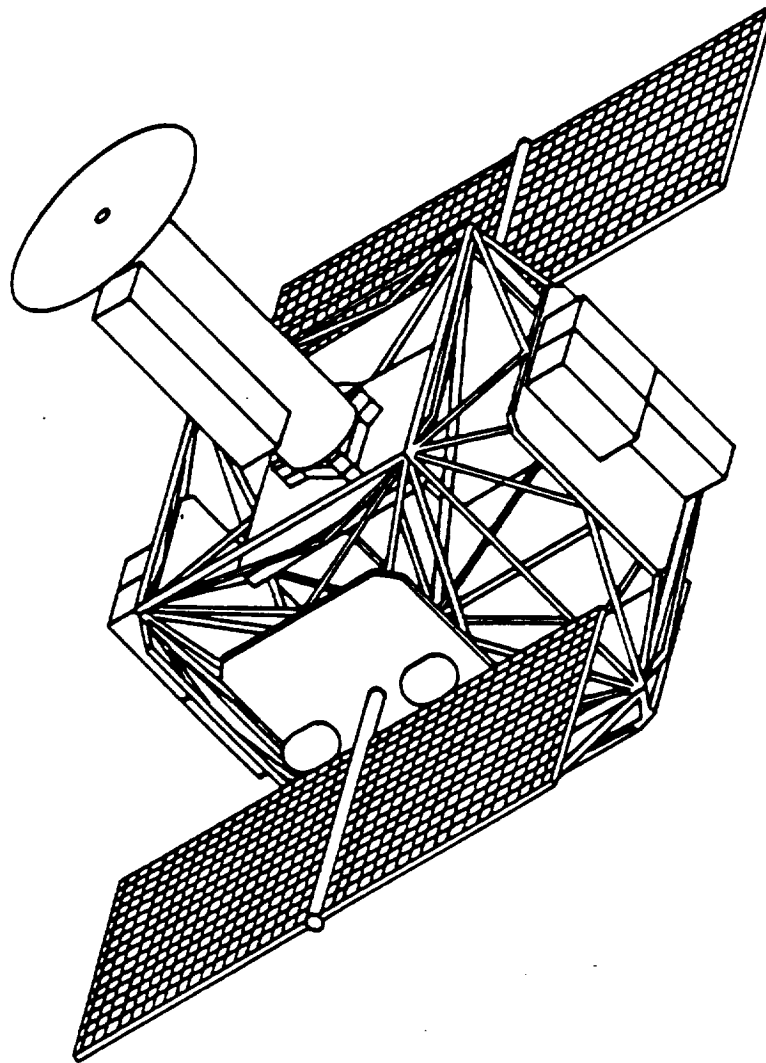
OSSTT 82D  
NASA SP-83-216 (3)  
12 13 88



# SKP TRUSS DERIVATIVE CONFIGURATION (WITH HRSO)

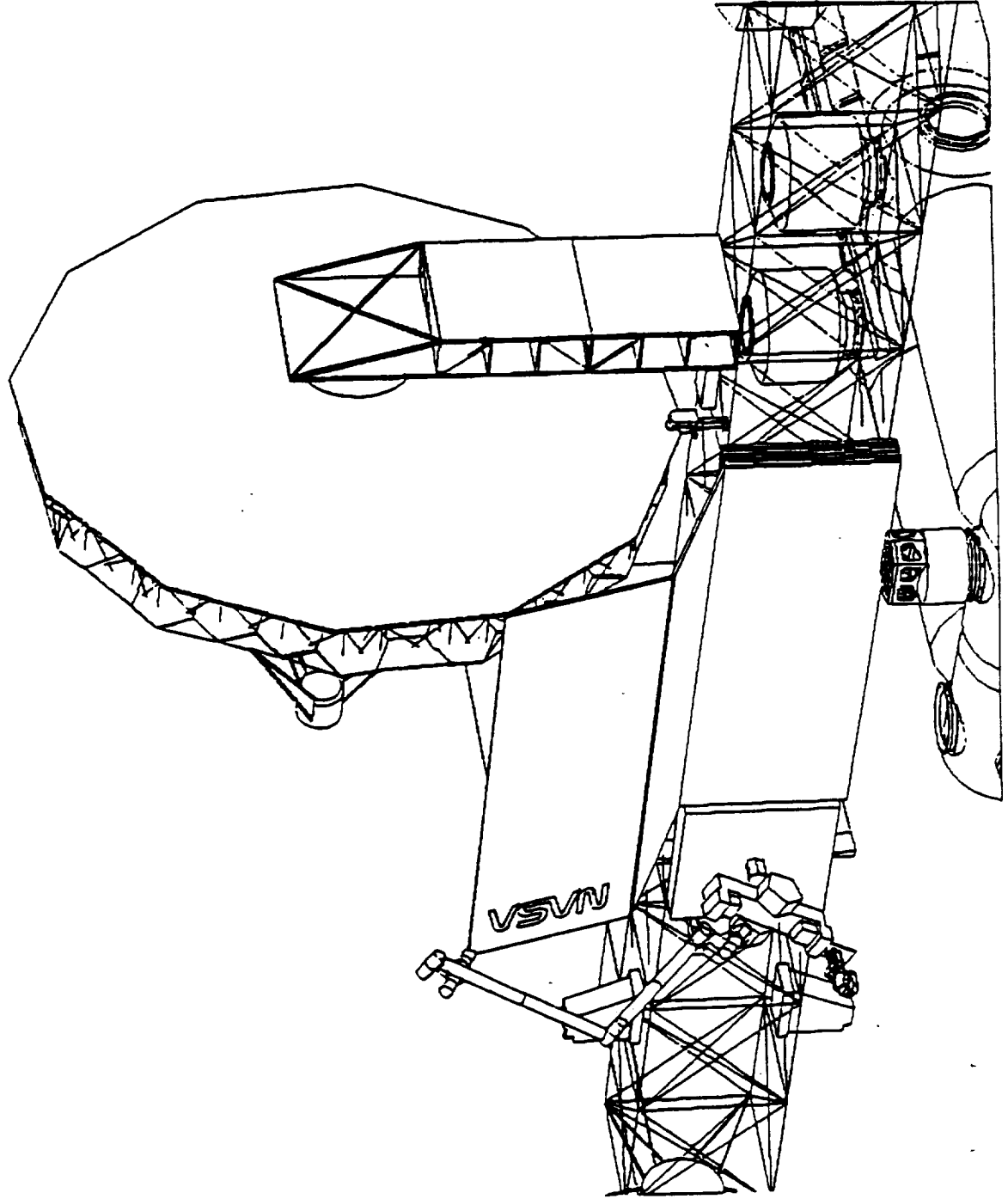
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SSU 8814303  
1582 12/04/88 M/CW

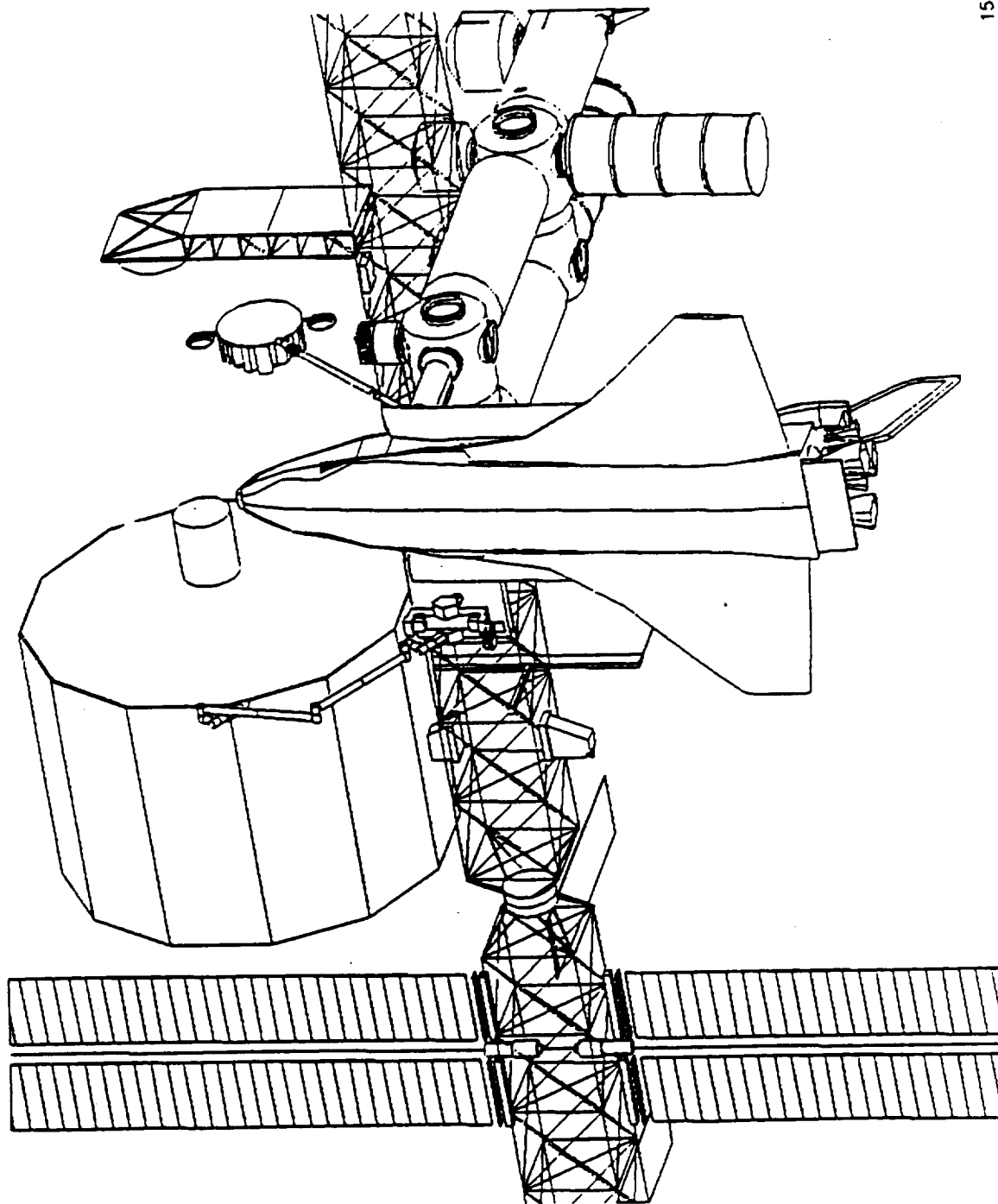
# Assembly of Large Deployable Reflector - I



SSU-8814319  
1500 12/11/88 M/I/IC

## Assembly of Large Deployable Reflector - II

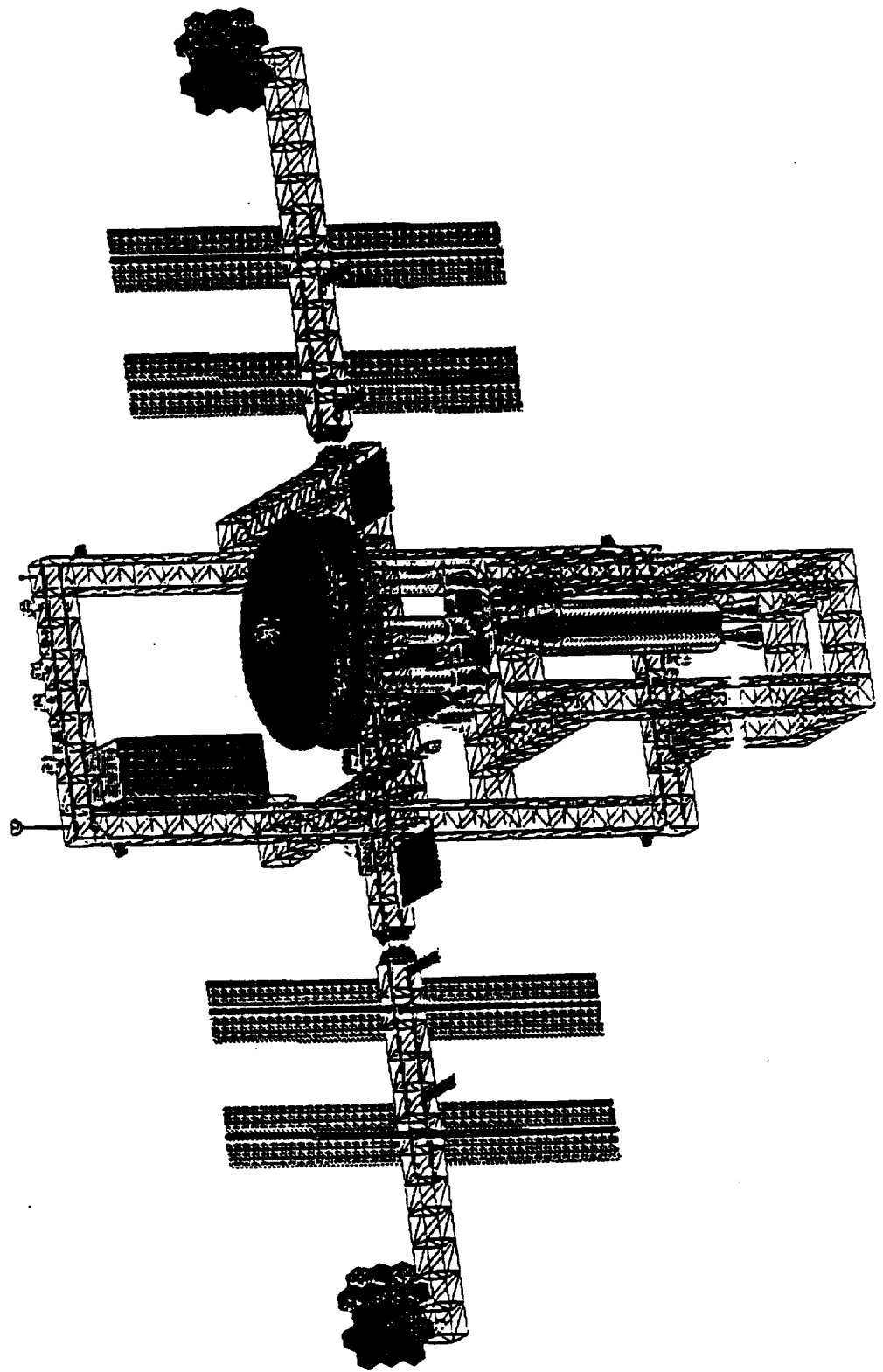
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SSU-8614318  
1582 12/04/88 M/JF

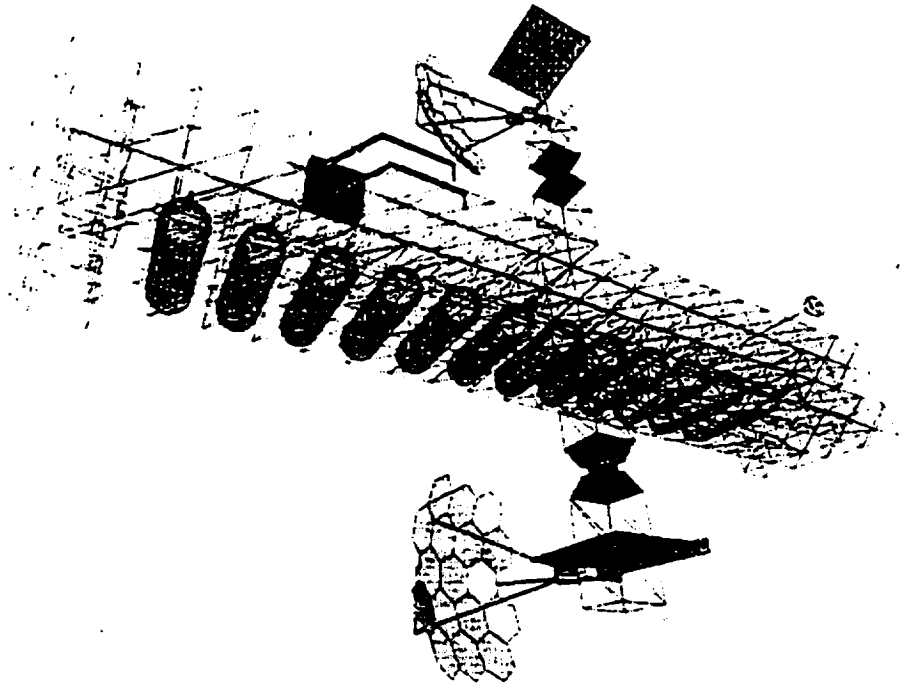
# SPACE STATION WITH CANDIDATE MANNED MARS CONFIGURATION

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Manned Mars Accommodation Study  
**PROPELLANT TANK FARM**

**CO-ORBITING PROPELLANT TANK FARM RECOMMENDED TO  
STORE AND TRANSFER PROPELLANTS FOR MANNED MARS  
MISSION**



**CAPACITY**

**1.9 M LB H<sub>2</sub> - O<sub>2</sub>**

**12 TANKS 16' X 60'**

## Process Description

- SCOPE

- ◊ End to End User Integration Is the Process Which:
  - ▼ Enables a User to Conduct Research, Development or Commercial Activities on the Station.
  - ▼ Includes All Interactions Between the SSP and the User/User Sponsors
  - ▼ External Activities Beginning with the User's Initial Contact With the SSP and Continuing Until Exit from the Program.
- ◊ The Integration Process Shall Provide a "Level Playing Field", with Payloads having similar Physical and Operational Requirements following the Same Path.

## Process Description

- **PROCESS DEVELOPMENT GOAL:**
  - ◊ **Provide a Process for User Integration Which:**
    - ▼ **Supports a Diverse User Community, Including Rapid Response Research (QIB)**
    - ▼ **Enables high priority research and development supporting national objectives and future missions.**
    - ▼ **Minimizes the Burden on the Users (Data, Meetings, etc.)**
    - ▼ **Provides single point of contact for Shuttle and Station Integration**
    - ▼ **Does Not Compromise Safety**
    - ▼ **Incorporates Lessons Learned from Past Programs**
    - ▼ **Recognizes Constraints Imposed by the Physical Requirements of Payload Integration**

## **Integration Process Overview**

- **Consider as Multiple Processes :**
  - ◊ **Payload Accommodation Assessment**
    - Verify station or platform capabilities can accommodate payload requirements
    - Identify deficiencies and potential station enhancements or potential reduction in payload requirements required
  - ◊ **Payload Development**
    - Payload DDT&E Conducted by Developer, PI
    - Driven by Experiment Goals, Development Resources
  - ◊ **Analytical Integration**
    - Engineering Analysis (Loads, Thermal, EMI, Contam., etc.)
    - Verify S/W Design
    - Analytical Support of Certification/Verification
  - ◊ **Payload Integration, Test & Verification**
    - Safety Certification
    - Verify P/L Design for Transportation, On-orbit Ops
    - Ensure that P/L Ops, Failures Will Not Endanger Crew, Station, Other Payloads (FMEA's, Failure Propagation, Debris Impacts, Etc.)



## User Support Features

- ◇ Standardized Flows for Payload Classes
  - Payloads Integration Flows Optimized for Level of P/L Complexity
  - Streamlined Flows for Rapid Response Research Payloads
    - Payloads Meet Pre-defined Constraints
    - Users of Existing Facilities
- ◇ **Payload Accommodations Manager**
  - Single Point of Contact Between User/Sponsor & SSP
  - Assists User During All Phases After Selection
- ◇ **Science & Technology Centers**
  - Conduct Tests, Modelling, Physical Integration for User
  - Both Gov't and Commercial (NASA Approved) Entities
- ◇ **Payload Operations**
  - Payload Operations Conducted by User (Telescience)
  - Overall Coordination, Safety Monitoring Provided by POIC
  - Distributed User Locations
- ◇ **Computer Supported Document Preparation, Reviews**
  - Use of Expert Systems as Appropriate ("Smart Documents")

## **Integration Process Overview Con't**

- ◇ **Physical Integration**
  - Perform Required P/L to Rack, Carrier Integration
- ◇ **Payload Operations**
  - On-orbit Payload Installation & C/O
  - Conduct Experiment Runs, Gather Data
  - Telescience & On-orbit Control
  - Safing, Deintegration & Return to Developer
- ◇ **Post Flight Debriefing, Lessons Learned, and Data Analysis**

## "Beat The System"

### ◇ TWO PATHS TO SIMPLE INTEGRATION, RAPID FLIGHTS

- Use an Existing "Facility Class Payload"
  - ¶ Freedom is a Long Duration "Orbital International Research and Development Lab"
    - Analogous to: Argonne National Laboratory, LaRC, Kitt Peak, LeRC, etc.
  - ¶ Major Facilities and Lab Support Equipment Available:
    - Truss Payload Accommodation Equipment, Payload System, Mobile Servicing Center, Flight Telerobotic Servicer, SS Furnance Facility, EVA Servicing, Glovebox, etc.
  - ¶ Use of Existing Facilities Requires Integration of Sample, Procedures: No DDT&E, Certification of Unique Hardware

### • Design/Build an "R"<sup>3</sup> Payload

- ¶ "R"<sup>3</sup> = Rapid Response Research: Payloads Defined to Established Guidelines (extension of GAS, STS Mid deck) :
  - ¶ Simple, Standard Interfaces
  - ¶ Modest Resource Requirements
  - ¶ Standard Req'ts for Safety, Physical Integration, Crew Support
  - ¶ Both Internal and External

## Space Station User Integration Process

### SPACE STATION FREEDOM UTILIZATION & OPERATIONS

SSU

#### User/Payload Integration Complexity

**Longest Duration**  
(2 - 5 Years)

◇ User Designs/Supplies Facility Class  
(Multiple User) Payload for Station

◇ User Designs/Supplies Standard  
(Single User) Payload for Station

◇ User Modifies Facility P/L Hardware,  
Software and Operations and  
Provides Samples, Specimens

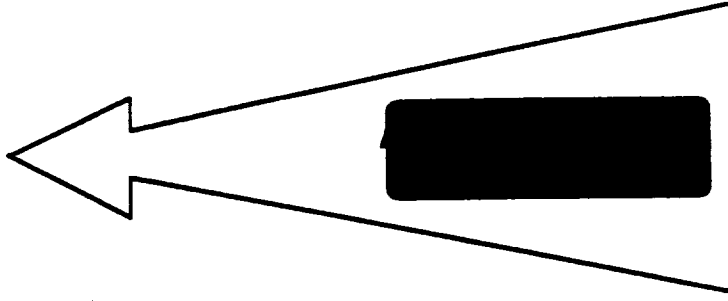
◇ User Designs/Supplies R<sup>3</sup> Payload

◇ User Modifies Existing Facility  
Payload Software and Operations,  
Provides Samples

◇ User Modifies Facility Operations and  
Provides Samples, Consumables

**Shortest Duration**

**Most Complex**



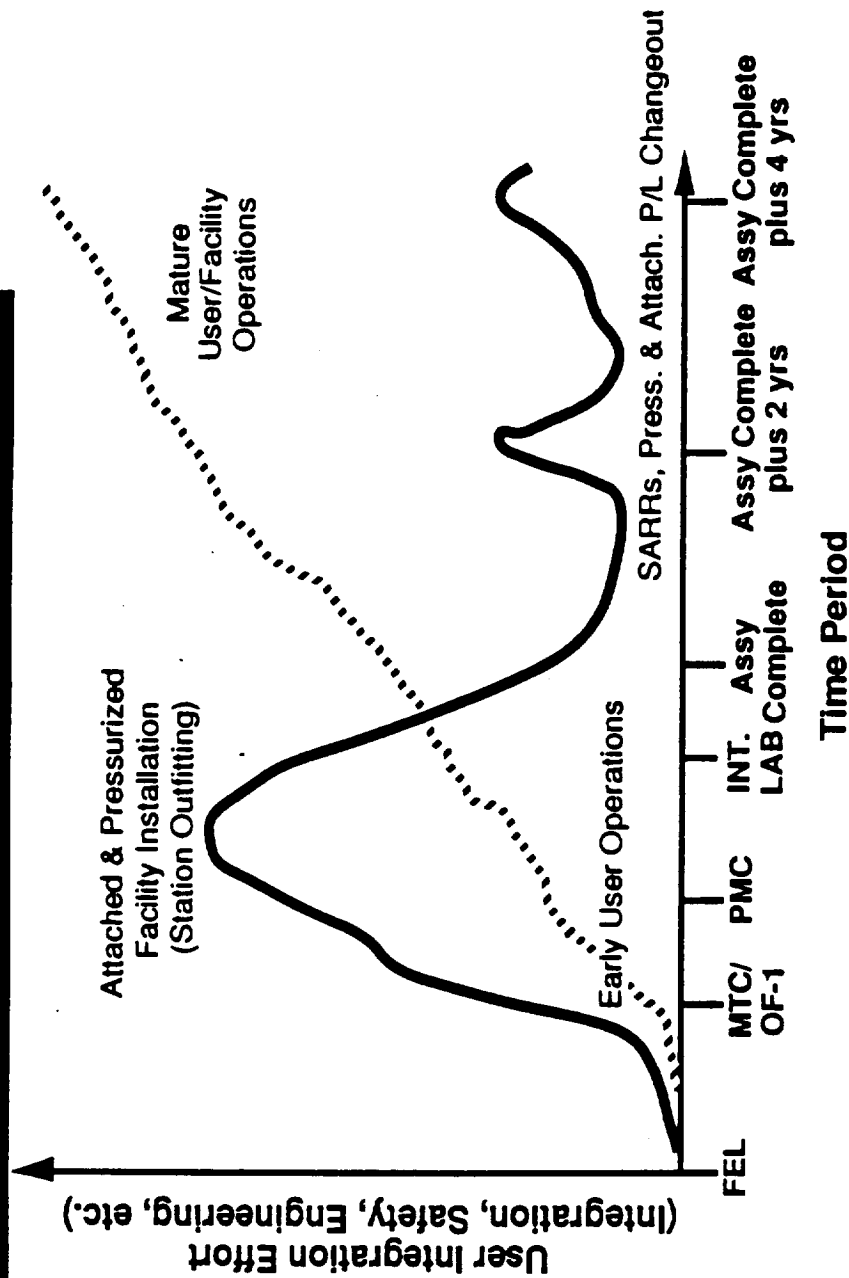
**Least Complex**

# Space Station User Integration Process

SPACE STATION FREEDOM  
UTILIZATION & OPERATIONS

SSU

## Existing Facilities Use Dominates Mature Operations

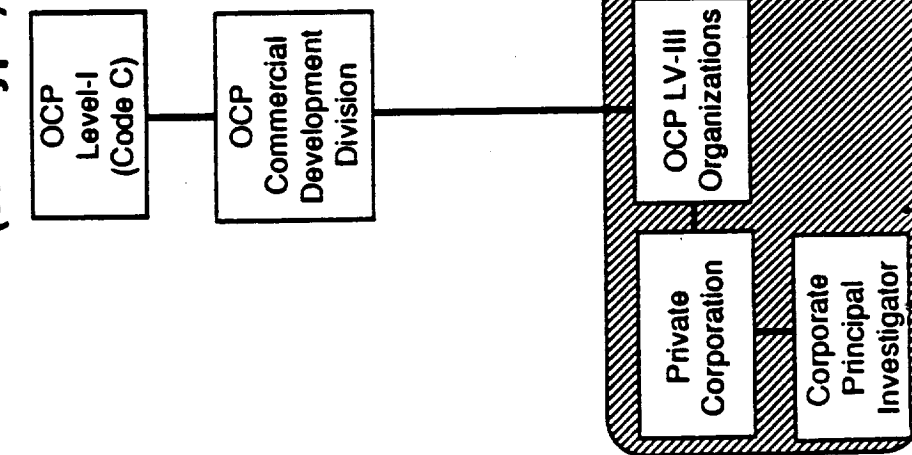


Traditional "Payload/Mission Integration" for hardware being shipped to/from Orbit

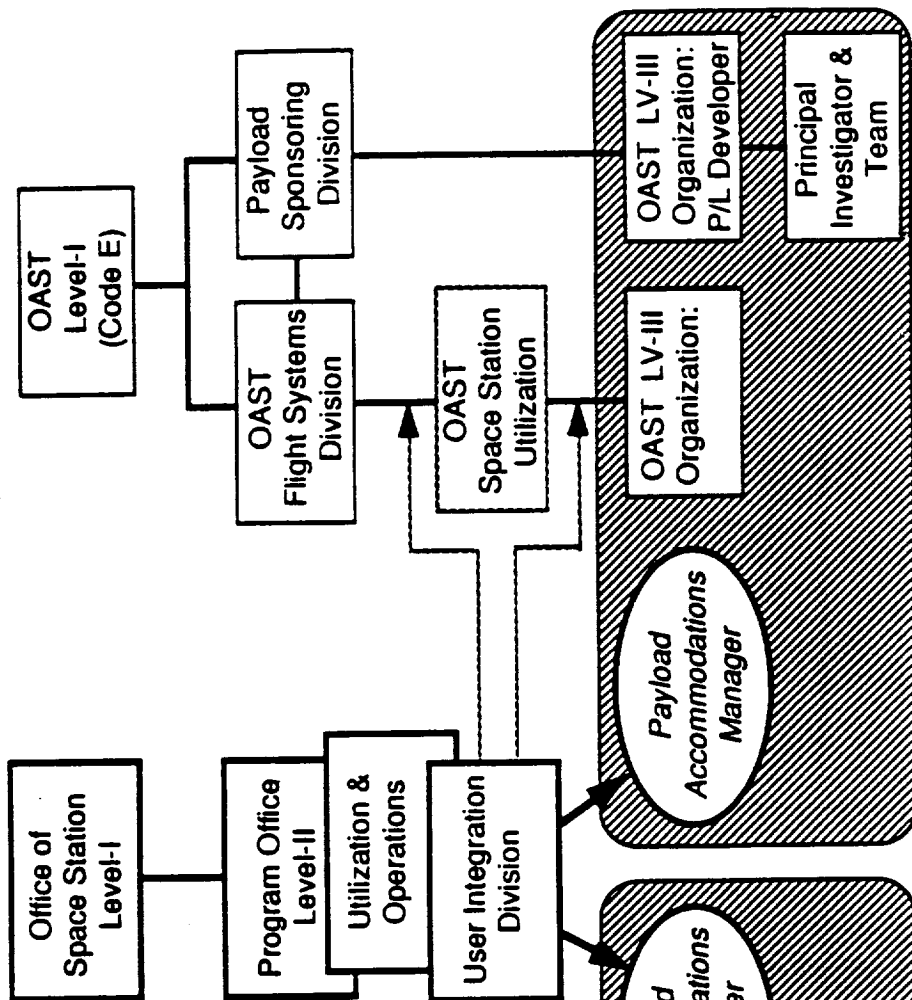
"Reconfiguration" of on-Orbit Facilities/Payloads to support Multiple User Operations (includes shipment/changeout/use of technology units, specimens, samples and consumables)

## Examples of Station-to-User Interface:

## Commercial Cooperative (JEA Type)



# Government Technology (NASA OAST Type)



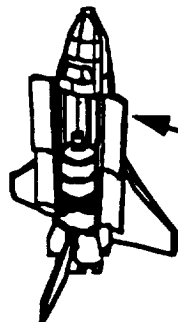
# Space Station User Integration Process

## SPACE STATION FREEDOM UTILIZATION & OPERATIONS

SSU

### User Operations Architecture

NSTS/Spacelab

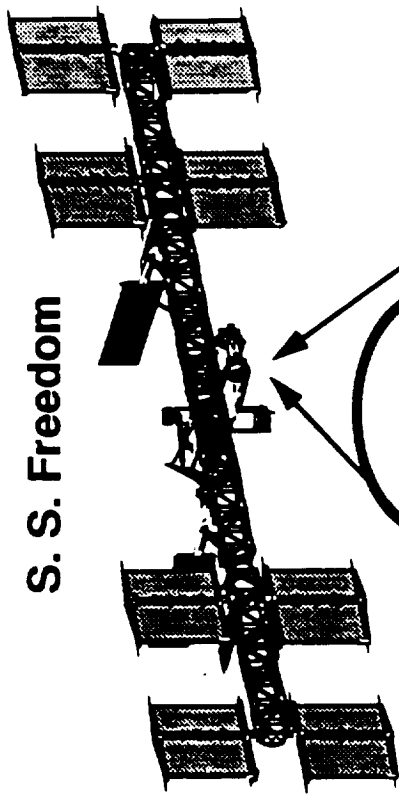


Mission Control Center (MCC)  
NASA/JSC

Centralized C&C

Payload Operations Control Center (POCC)  
NASA/MSFC

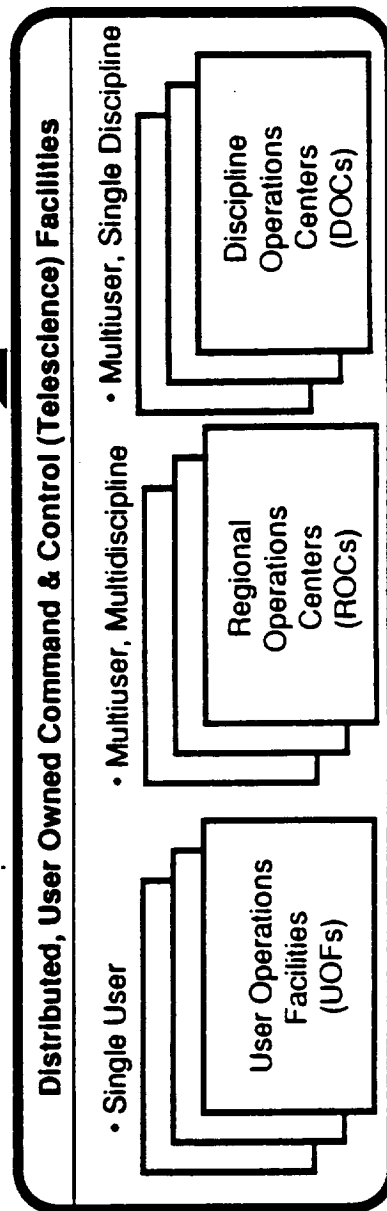
S. S. Freedom



Coordination & Safety

Space Station Control Center (SSCC)  
NASA/JSC

Payload Operations Integration Center (POIC)  
NASA/MSFC



## **SPACE STATION FREEDOM TECHNOLOGY PAYLOAD ACCOMMODATION**

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- PROVIDES FOR MULTIPLE TYPES AND SIZES OF TECHNOLOGY R.&D. OPPORTUNITIES
  - QUIET AND ACTIVE ENVIRONMENTAL CONDITION PERIODS CAN BE SCHEDULED
- SPACE STATION FREEDOM, TOGETHER WITH CO-ORBITING PLATFORM TEST FACILITIES, CAN FUNCTION AS A MAJOR TEST BED FACILITY
  - TO SUPPORT INTERPLANETARY SPACECRAFT R.&D.
  - TO SUPPORT LUNAR/MARS BASE TECHNOLOGY AND SYSTEMS R.&D.
- SPACE STATION FREEDOM USER INTEGRATION AND PAYLOAD ACCOMMODATION PROCESSES WILL BE ESTABLISHED
  - TO INSURE RAPID AND SUCCESSFUL INTEGRATION OF TECHNOLOGY PAYLOADS
  - WILL ENABLE "SKUNK WORKS" R.&D. IN SPACE.



## **KEYNOTE ADDRESS**

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## MISSION TO EARTH, MOON, AND MARS

Harrison H. Schmitt

Let us jump ahead to late January, 1990, and try to anticipate what should be the concluding paragraphs of the President's State of the Union Address to the Congress.

"Now, my fellow Americans, as your representatives assembled in these historic chambers know so well, there has been a rising tide of domestic and international political pressure in support of initiatives for the future. You have made us all increasingly aware that both vulnerabilities and opportunities in America's future and in the future of humankind require our urgent attention. The unfair inequities of the present still do and will always demand our concern and our compassion, however, many issues essential to the future well-being of our children and our country have been too long neglected.

"Therefore, over the next 60 days, I will send to the Congress a number of proposals that address long term structural changes in our approaches to education, the environment, retirement and health security, basic research, and other critical areas.

"Tonight, because of the central roles played by environment and space in the future of our children, I am calling on the Congress to provide the long term commitments necessary to undertake a specific project focused on the turn of the Third Millennium. Although this rare milestone is only 10 years away, the challenge has grown to for a Millennium Project that will match the times and the opportunities.

"Our Millennium Project, in which we invite the family of nations to join, will be the establishment of a permanent human outpost on Mars by 2010 and, by so doing, provide the technology base necessary to preserve the Earth's global environment.

"The creation of a permanent outpost on Mars will have as its primary purposes the eventual settlement of the planet Mars by free human beings and the provision of abundant and environmentally benign electrical power on Earth. The bridge between these two essential achievements is the development of helium-3 fusion

power plants on Earth fueled by the helium resources of the moon. This bridge of energy also provides, as by-products from the energy resources of the moon, the oxygen, hydrogen, and other consumable materials critical to sustaining the early settlers of Mars.

"Thus, our Millennium Project combines space ventures to the Earth, moon, and Mars into a single great human mission -- a mission to save the atmosphere, waters, and rainforests of Earth, a mission to settle the moon and utilize its resources for the benefit of all, and a mission to establish human civilization and freedom permanently on Mars.

"A draft treaty for international participation in The Millennium Project is being circulated among the nations of Earth. This treaty, tentatively called the INTERMARS Charter, proposes a participant based relationship between nations, users, and investors, modeled after the successful International Telecommunications Satellite or INTELSAT Agreements. It is the intention of the United States Government that an international conference to finalize the INTERMARS Charter will be convened by interested nations before the end of the year.

"Ladies and gentlemen and my fellow Americans, our commitment to the success of The Millennium Project must be unequivocal. It must include an equally unequivocal commitment to carry the sacred institutions of freedom with us as humankind expands into its larger home among the planets and the stars."

The recent return of American astronauts to space, as satisfying as it must be to those of you responsible, constitutes but a very small step in the repair of what can only be called a space policy disaster.

Challenger and the tragedy of its loss did not cause this policy disaster nor was it caused by the dedicated people of NASA and its contractors whatever errors in judgment may have been made. The now so obvious loss of momentum in the United States space program has been the result of a loss of will on the part of national leadership spanning almost two decades.

Humankind's first explorations of the moon and of space near the Earth between 1968 and 1972 were also the species first clear steps of evolution into the solar system and eventually into the galaxy. As the Pueblo Indians tell the lesson of their ancestors, "We walk on the Earth, but we live in the sky."

Early explorers of the sky not only took their eyes and minds into space and became the eyes and minds of billions of other explorers on the starship Earth, but they began the long process of transplanting civilization into space. This fundamental change in the course of history has occurred as humans also have gained new insight into themselves and their first planetary home.

Limitless seas in space exist not only as new frontiers but as new challenges for humankind. The nations on Earth which effectively utilize technology to exploit the economic and military advantages of the new ocean of space will dominate human activities on this planet well into the next century, if not indefinitely. Those nations also will provide the irreversible templates for the social and political evolution of civilization beyond the next century far into the Third Millennium.

The first response to this challenge in space by the United States under President John F. Kennedy's leadership appeared to recognize the historic proportions of the contest. The leading involvement of the United States in space initially insured that the traditions of free institutions would be represented. As a consequence, at the high point of the Apollo Program, the United States verged on the establishment of bases on the moon, research stations in earth orbit, and the statement of a realistic goal of a foothold on Mars by the end of the Century. In the motto of the last Apollo mission to the moon in December 1972, the conclusion of the Apollo Program truly could have been "The End of the Beginning."

The opportunity given to humankind by the Apollo Program and its generation passed by. Consequently, the responsibility to re-ignite Kennedy's torch for space falls to others. The emotional energy to light that torch could be supplied to generations now alive by the vision of the human settlement of Mars and by the necessity of providing vast amounts of environmentally compatible energy for the billions of humans left at home.

The return of Americans and their partners to space must be viewed in the context of the free world's over all perception of the future of humankind. In the United States, unfortunately, little political thought normally is given to that future or to our role with in it. However, in space, we have little choice. The United States will be the free world's principal agent and advocate in space, because there are no other likely alternatives.

One body of opinion in the U.S. today would argue that there is no hurry. "Space will always be there, and meanwhile we have more pressing near term interests here on Earth. What is interesting to do scientifically can be done with robots at

much lower cost." Unfortunately for those who hold this opinion, times are changing rapidly, and there is history being made without us. The challenge in space can no longer be viewed as merely a scientific challenge as valuable as the science to be done will be. The challenge now is to both lead the human settlement of space and the environmental preservation of our home planet.

Why the hurry? Why stretch human technological and psychological reach to the limit? First and foremost, the answers are in the minds of young people who will carry us into the Third Millennium. The answers are in the generations now in school, now playing around our homes, now driving us to distraction as they struggle toward adulthood. They will settle the moon and then Mars. They will do this simply because they want to do this. They want to "be there". "Being there" remains the essential human ingredient in life's meaningful experiences.

The desire to "be there" will drive our young people away from the established paths of history on a now too confining Earth. It will take them and their progeny to an infinity of opportunity among the planets and the stars. Video pictures and data streams from robots on Mars, no matter how good or how complete, will never be enough for the parents of the first Martians. Somewhere, those parents are alive today. Whether they now play on the steppes of Russia, on the river banks of China, or on the mountains, plains, and shores of America, or on a combination of all three, constitutes the most critical question of national will we face today.

Thus, an answer to "why the hurry" also lies in the clear determination of the Soviet Union to establish its sovereignty in deep space and on Mars before the forces of freedom do so. The permanently occupied MIR space station, very long duration earth orbital flights by the cosmonauts, heavy lift launch vehicle testing, and their public emphasis of Mars exploration, leading to human visits early in the 21st Century, all tell us what the Soviets expect to do. In spite of all the real and perceived difficulties faced by the Soviet Union in the future, there is now reason to count on their failure in space.

Perhaps the most important answer from the perspective of the physical welfare of the human species lies in the absolute moral and political requirement to provide the ever expanding population of Earth with an ever improving quality of life. We do not currently have the technical means to do this. We do not know how we are going to provide the ten billion human beings expected before the end of the 21st Century with both the hope and the reality that they will have defeated the four horsemen of worldwide disaster: poverty, hunger, disease, and ignorance. The essential ingredient for victory in this very human battle is environmentally

compatible energy. Fossil fuels, the rainforests, and conventional nuclear power cannot provide the answer without either unexceptable political conflict or potentially devastating consequences to the biosphere of the Earth.

Fusion power plants fueled by helium-3 from the moon (Wittenberg, 1986) could supply the electrical energy human civilization will require to maintain and expand human quality of life as we enter the Third Millennium. Inherently safe and potentially low cost fusion reactors fueled by lunar helium-3 also could become the basis for producing large quantities of continuously available electrical power in space, for highly efficient space propulsion to and from Mars, and for life giving by-products that insure the self sufficiency of settlements on the moon and Mars (Kulcinski, 1987).

Furthermore, establishment of a permanent settlement on the moon, based on the production of helium-3 for use as an energy source on Earth fully supports the desire to live on Mars as soon as possible.

First of all, most of the technology needed for the creation of a permanent lunar settlement with a resources production economy will support the technological requirements for establishing a Martian settlement. The compatible technologies include heavy lift launch vehicles, long duration surface habitats and mobility systems, resource production facilities, regular and routine capability to work in a hostile and dusty environment, and new concepts in equipment automation, reliability, longevity, and maintainability.

Second, the direct and indirect by-products of helium-3 production from the lunar surface materials will provide a ready source of necessary consumables for Martian inhabitants prior to and possibly even after the creation of their own consumables industry. These lunar produced consumables include hydrogen, oxygen, nitrogen, carbon, and food.

A preliminary estimate of the energy equivalent value of helium-3 today is about two billion dollars per metric tonne if matched against the cost of coal currently used to produce electricity in the United States. This is roughly equivalent to \$14 per barrel oil at today's prices. Two billion dollars worth of fuel currently supplies the electrical power needs of the United States for about two weeks or of a city of 10 million for about one year. The foregoing estimates of value do not take into account the additional value of by-products from lunar helium-3 production or the spin-off value of related technologies.

The principle advantages of the helium-3 fusion power cycle on Earth over other nuclear cycles include:

1. About 99 percent of the energy released is in charged particles (protons) that induce no radioactivity in other materials.
2. High efficiency (70-80 percent) in energy conversion due to the potential for direct conversion of protons to electricity.
3. Less waste heat to be rejected due to high efficiency.
4. The energy of each of the few neutrons released (1 percent of total energy) is only one-fourth that released in other fusion cycles and such neutrons create no significant quantities of long lived radioactive waste.
5. A potentially shorter time to licensed commercialization than for other fusion cycles due to the absence of significant radioactivity and waste heat.

Estimates of the ultimate steady-state costs of delivering helium-3 to deuterium/helium-3 power plants on Earth run about one billion dollars per metric tonne. If such cost prove to be correct, such power plants will provide much lower cost electricity as well as much less environmental impact than other competing power sources proposed for the 21st Century.

The only major technical disadvantage of the deuterium/helium-3 fusion cycle is that the ignition temperature and confinement pressure required to initiate fusion is about four times higher than for the competing deuterium/tritium cycle. This disadvantage appears to be becoming less and less significant as new fusion confinement technologies are developed. In fact, a recent test in Great Britain produced a record 60 kilowatts of fusion energy using deuterium and helium-3 (G.L. Kulcinski, personal communication).

Sufficient helium-3 is available on Earth (largely from tritium decay and natural gas) for development and prototype testing of deuterium/helium-3 power plants. Therefore, the primary issues that must be addressed to determine the feasibility of a commercial helium-3 industry are, first, the technical and economic feasibility of deuterium/helium-3 commercial reactors and, second, the technical and economic feasibility of providing lunar helium-3 to fuel such reactors.

Historically, major extensions of the benefits of civilization have built on extensions of the existing



foundation of scientific and technical understanding. The creation of the pyramids, the aqueducts and roads of the Roman Empire, the Gothic Cathedrals, the industrial revolution, the airplane, the construction of the Panama Canal, the green revolution in agriculture, and controlled nuclear energy have followed this pattern. No less than these examples, Apollo exploration of the moon and the technological revolution brought about by space flight matched the experience and technology of the past with the imagination and research of the moment.

New explorations at the frontiers of space, that is, in places and for times that are significantly beyond the technical capabilities of Apollo, Skylab, the Space Shuttle, and the space station also will require new technologies to augment those necessary to live and work in near Earth space. New and more rapid interplanetary rockets and new concepts of life support, mobility, and transportation will obviously be necessary. Foresight will be required to invest a reasonable proportion of available resources in these essential new technologies.

In the political climate of the last two decades, however, it is probably appropriate to ask, "do the discussions of future large scale space activities have any actual relevance in the United States today?" This question is particularly topical in view of the very limited commitment to major space activities put forth in the recent congressional and presidential campaigns.

Positive indications of the relevance of discussions related to space are found in the interest and motivation of a core of a few tens of thousands of technical, scientific, and philosophical advocates, in the extraordinary qualitative support of the American people for the space program, and in the historical imperative space imposes on free men and women.

Polls and surveys indicate that 75% or more of the American people support a strong space program. 75% support for anything is almost beyond rational explanation. Space has the potential to excite and motivate almost anyone.

Even if this overwhelming qualitative support did not exist, the question would still have to be asked, "if the Americans do not insure that free institutions are established elsewhere in the solar system, who else will guarantee that they will be?" Further, "if the Americans do not insure the ultimate survival of the Earth's biosphere, who else will guarantee that survival?" These fundamental points have been missed in almost all political and technical debates on the future course of the U.S. space effort.

Unfortunately, the indications of a lack of current political relevance of any discussion about advanced space

technology are staggering as any regular reader of Aviation Week and the Wall Street Journal will soon discover.

First, few candidates for political office feel any need to address civilian space activities as a significant philosophical, political, or environmental issue. Nor do they feel the need to address any of the broad spectrum of other critical issues of the future. The short term vested interests dominate their view because that is where elections and re-elections are won or lost.

Second, in spite of tentative commitments to it, the space station may lose its battle for domestic and international legitimacy -- on the one hand, the Administration has failed to make an unequivocal domestic political case for a U.S. managed space infrastructure and, on the other hand, the Soviets have a ten year lead in space station capability with the permanently occupied MIR station already in orbit.

Third, a U.S. heavy lift launch capability, critical to so many aspects of the future in space, does not exist. Again, the Soviets have a ten year lead in such capability which now includes an apparently competitive space shuttle.

Fourth, no significant resources are being allocated to recasting the free world's space agenda toward the settlement of Mars while, once again, the Soviets have at least a ten year lead in planning and developing such a capability.

Fifth, many national leaders are committed to severe limitation on the development of strategic defenses while the Soviets appear to be nearing a strategic defense breakout in ground based systems.

Sixth, our national leaders as well as the armed services have been unable to recognize the values of integrated manned and automated space based systems in tactical and strategic defense doctrines while the Soviets continue to develop and exercise their decades old commitment to an integrated Earth and space military doctrine. As the CINCSpace, General Piotrowski, has said recently, the Soviets can rapidly and effectively exercise control of space -- the U.S. cannot do so.

Seventh, no workable policy exists that would insure that the U.S. and its allies would have an assured supply of critical energy and materials and the related industrial base necessary to sustain either long term space activities or near term defense and economic activities (Mott Committee, 1988). Indeed, no national leader appears to recognize that this is even an issue, witness the limited factual basis for proposals related to southern Africa.

Even this list does not tell the whole terribly sad story as many of you know better than I.

How did we fall so far from the dizzy heights of Apollo? 1970 was the fateful year history must mark as the year the nation's political leadership began to let our space momentum and maybe our national destiny slip away.

Ironically, the people of Apollo, in spite of their spectacular success in meeting President John Kennedy's challenge, "to put men on the moon and return them safely to Earth," had lost the media and political support necessary to build on their accomplishments.

Once Apollo missions began to be canceled and the industrial base to utilize the Apollo technology base started to be dismantled, the opportunity to lead humankind into space began to slip away. Even the reluctant decision by the Nixon Administration to build the Space Shuttle, and the equally reluctant decision by the Carter Administration to continue, were made out of context relative to any grand design for our future in space. The underfunding of the Shuttle development program, by at least a factor of three less than prudent estimates of the time, was the direct consequence of this hesitant and uncomprehending political environment. The seeds of the Challenger accident were sown by these events. Their tragic harvest sixteen years later is a stark indictment of all who let this drift in space policy begin and continue.

America, like Ebenezer Scrooge, still has time to change this specter of history yet to come. So, rather than conclude on the preceding pessimistic recital of history and current reality, let me return to the areas of technological challenge before America and the possibilities for progress before the humankind by referring back to the hypothetical State of the Union Address.

"Our Millennium Project combines space ventures to the Earth, moon, and Mars into a single great human mission -- a mission to save the atmosphere, waters, and rainforests of Earth, a mission to settle the moon and utilize its resources for the benefit of all, and a mission to establish human civilization and freedom permanently on Mars.

"Our commitment to the success of The Millennium Project must be unequivocal. It must include an equally unequivocal commitment to carry the sacred institutions of freedom with us as humankind expands into its larger home among the planets and the stars."

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*Harrison H. Schmitt*

Harrison H. Schmitt

P.O. Box 14338  
Albuquerque, NM 87191-4338  
(505) 823-2616

#### BIOGRAPHICAL SKETCH

Harrison "Jack" Schmitt has the varied experience of a geologist, scientist, astronaut, pilot, administrator, educator, writer, and United States Senator.

He trained as a geologist and scientist at the California Institute of Technology, as a Fulbright Scholar at the University of Oslo, and at Harvard University, receiving his PH.D. in geology from Harvard in 1964 based on earlier field studies conducted in Norway.

He was selected for the Apollo Scientist-Astronaut program in 1965 and served as the Lunar Module Pilot for Apollo 17--the last Apollo mission to the Moon.

Schmitt's studies of the Valley of Taurus-Littrow on the Moon in 1972, as well as his earlier scientific work, made Schmitt one of the leading experts on the history of the terrestrial planets. As the only scientist to go to the Moon, he was also the last of twelve men to step on the Moon.

After organizing and directing the activities of the Scientist-Astronaut Office and of the Energy Program Office for NASA in 1973-1975, Schmitt fulfilled a long-standing commitment by entering politics. He was elected to the U.S. Senate from his home state of New Mexico in 1976.

In his last two years in the Senate, Senator Schmitt was Chairman of the Senate Commerce Committee's Subcommittee on Science, Technology, and Space and of the Senate Appropriations Committee's Subcommittee on Labor, Health and Human Services, and Education. He currently serves as a member of the Army Science Board and as consultant to the National Strategic Materials and Minerals Program Advisory Committee.

Harrison Schmitt is consulting, speaking, and writing on a wide range of business, foundation, and government initiatives. His principle activities are in the fields of technology, space, defense, biomedicine, geology, and policy issues of the future. He brings to the consideration of complex public and corporate concerns a unique breadth of experience ranging from the scientific to the practical and from the administrative to the political.

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CRITICAL IN-SPACE TECHNOLOGY NEEDS

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**SPACE STRUCTURES  
CRITICAL IN-SPACE TECHNOLOGY NEEDS**  
**MARTIN MIKULAS, JR.**  
**LANGLEY RESEARCH CENTER**

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SPACE STRUCTURES	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	STRUCTURES
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# SPACE STRUCTURES

## THEME ELEMENT #1 : STRUCTURES

1. SYSTEM IDENTIFICATION
  - QUASI-STATIC
  - DYNAMIC
2. VERIFICATION OF PREDICTION METHODS
3. ERECTABLE STRUCTURES CONSTRUCTION
4. PRECISION SENSOR DEVELOPMENT
5. STRUCTURAL INTEGRITY

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

SPACE STRUCTURES	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CONTROL/STRUCTURE INTERACTION & CONTROLS
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

### SPACE STRUCTURES

#### THEME ELEMENTS #2 & 3 : CONTROL/STRUCTURE INTERACTION & CONTROLS (COMBINED)\*

1. FLEXIBLE MULTI-BODY/ARTICULATED CONTROL
2. PRECISION POINTING AND SHAPE DIMENSIONAL CONTROL
3. MULTIPLE INTERACTING CONTROL SYSTEM
4. DAMPING AND VIBRATION SUPPRESSION
5. VIBRATION ISOLATION

\*RECOMMENDATIONS: EXPERIMENTS SHOULD BE MULTIDICIPLINARY IN NATURE  
AND PREFERABLY IN THE FORM OF REUSABLE TEST BEDS..

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

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# **SPACE ENVIRONMENTAL EFFECTS CRITICAL IN-SPACE TECHNOLOGY NEEDS**

**LUBERT J. LEGER  
JOHNSON SPACE CENTER**

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SPACE ENVIRONMENTAL EFFECTS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ATMOSPHERIC EFFECTS AND CONTAMINATION
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### CRITICAL IN-SPACE TECHNOLOGY NEEDS

## SPACE ENVIRONMENTAL EFFECTS

### THEME ELEMENT #1 : ATMOSPHERIC EFFECTS AND CONTAMINATION

1. ACTIVE MEASUREMENT OF ATMOSPHERIC CONSTITUENTS SUCH  
AS ATOMIC OXYGEN, TO SUPPORT STUDIES OF ALL ATMOSPHERIC  
INTERACTION PHENOMENA
2. GLOW PHENOMENA INFORMATION TO SUPPORT SENSOR DESIGN
3. CONTAMINATION EFFECTS AND ATOMIC OXYGEN EROSION DATA  
FOR MATERIAL DURABILITY ASSESSMENT FUNCTIONAL  
PERFORMANCE PREDICTION AND MODEL DEVELOPMENT AND  
VERIFICATION

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

SPACE ENVIRONMENTAL EFFECTS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MICROMETEOROID AND DEBRIS
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# SPACE ENVIRONMENTAL EFFECTS

## THEME ELEMENT #2 : MICROMETEOROID AND DEBRIS

1. CHARACTERIZATION OF THE LOW EARTH ORBIT DEBRIS ENVIRONMENT
  - PARTICLE SIZE DISTRIBUTION
  - MORE INFORMATION ON DEBRIS CHARACTERISTICS - SPECTRAL PROPERTIES, SHAPE, COMPOSITION
2. LONG TERM SURFACE DEGRADATION FROM DEBRIS
3. DEVELOP AND VERIFY COLLISION WARNING SYSTEMS TECHNOLOGY
4. EVALUATE AND VERIFY MITIGATION TECHNIQUES

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

SPACE ENVIRONMENTAL EFFECTS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CHARGED PARTICLES & ELECTROMAGNETIC RADIATION EFFECTS
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# SPACE ENVIRONMENTAL EFFECTS

## THEME ELEMENT #3 : CHARGED PARTICLES & ELECTROMAGNETIC RADIATION EFFECTS

1. BETTER CHARACTERIZATION OF RADIATION ENVIRONMENT IN POLAR REGION  
AND VAN ALLEN RADIATION BELTS & ASSOCIATED WITH SOLAR FLARE ACTIVITY
2. LONG TERM, CONTINUOUS MEASUREMENTS OF MATERIAL PHYSICAL AND  
ELECTRICAL PROPERTIES IN CRITICAL ORBITS FOR UNDERSTANDING OF  
INTERACTION MECHANISM AND VALIDATION OF GROUND BASED TESTING
3. DETERMINE THE EFFECTS OF GAS RELEASES IN LEO ON ELECTROMAGNETIC  
INTERACTIONS
4. DEVELOPMENT OF SIMPLE SMALL AUTONOMOUS SENSORS FOR MEASUREMENT  
OF SURFACE CHARGING, RADIATION EXPOSURE AND ELECTRIC FIELDS

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY



# **POWER SYSTEMS AND THERMAL MANAGEMENT CRITICAL IN-SPACE TECHNOLOGY NEEDS**

**ROY McINTOSH  
GODDARD SPACE FLIGHT CENTER**

POWER SYSTEMS & THERMAL MANAGEMENT	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	DYNAMIC AND NUCLEAR POWER SYSTEMS
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### CRITICAL IN-SPACE TECHNOLOGY NEEDS

## POWER SYSTEMS & THERMAL MANAGEMENT

### THEME ELEMENT #1 : DYNAMIC AND NUCLEAR POWER SYSTEMS

1. GAS COLLECTION AND RETENTION IN LIQ COOLANTS
2. FREEZE/THAW IN LIQ METAL SYSTEMS
3. GAS BUBBLE NUCLEATION/GROWTH IN LIQ METALS
4. TWO COMPONENT (SOLID/LIQUID) PUMPING/SEPARATION
5. TWO PHASE LIQ/GAS SEPARATION IN COOLANTS

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

POWER SYSTEMS & THERMAL MANAGEMENT	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CONVENTIONAL POWER SYSTEMS
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# POWER SYSTEMS & THERMAL MANAGEMENT

## THEME ELEMENT #2 : CONVENTIONAL POWER SYSTEMS

1. ADVANCED ENERGY STORAGE
2. ADVANCED P.V. CELL TECHNOLOGY
3. PRIMARY & REGENERATIVE FUEL CELLS
4. THERMAL ENERGY STORAGE
5. CONTAMINATION, UV & CHARGED PARTICLE PV EFFECTS

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

POWER SYSTEMS & THERMAL MANAGEMENT	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	THERMAL MANAGEMENT
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# POWER SYSTEMS & THERMAL MANAGEMENT

## THEME ELEMENT #3 : THERMAL MANAGEMENT

1. TWO-PHASE HEAT TRANSFER
2. HEAT PIPES (LIQUID METAL & CRYO)
3. CAPILLARY LOOPS
4. TWO-PHASE FLOW & STABILITY
5. VOID BEHAVIOR FLIGHT TEST

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

# **FLUID MANAGEMENT & PROPULSION SYSTEMS CRITICAL IN-SPACE TECHNOLOGY NEEDS**

**LYNN ANDERSON  
LEWIS RESEARCH CENTER**

<b>FLUID MANAGEMENT &amp; PROPULSION SYSTEMS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>ON-ORBIT FLUID MANAGEMENT</b>
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# FLUID MANAGEMENT & PROPULSION SYSTEMS

## THEME ELEMENT #1 : ON-ORBIT FLUID MANAGEMENT

1. FLUID TRANSFER
2. MASS GAUGING
3. THERMODYNAMIC VENT SYSTEM/MIXING
3. LIQUID ACQUISITION DEVICES
3. FLUID DUMPING/TANK INERTING
4. LIQUID DYNAMICS/SLOSH
5. AUTOGENOUS PRESSURIZATION
5. LONG TERM STORAGE

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

FLUID MANAGEMENT & PROPULSION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	PROPULSION
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# FLUID MANAGEMENT & PROPULSION SYSTEMS

## THEME ELEMENT #2 : PROPULSION

1. PLUME IMPACTS & CHARACTERISTICS
2. ELECTRIC PROPULSION SPACE TEST
3. MULTIDISCIPLINE SPACE TEST BED

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

<b>FLUID MANAGEMENT &amp; PROPULSION SYSTEMS</b>	<b>IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988</b>	<b>FLUID PHYSICS</b>
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## **CRITICAL IN-SPACE TECHNOLOGY NEEDS**

# **FLUID MANAGEMENT & PROPULSION SYSTEMS**

## **THEME ELEMENT #3 : FLUID PHYSICS**

1. LIQUID-VAPOR INTERFACES
2. POOL/FLOW BOILING
2. CONDENSATION/EVAPORATION
3. ADVANCING LIQUID FRONTS
3. BUBBLE/DROPLET DYNAMICS

**NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY**



**AUTOMATION AND ROBOTICS**  
**CRITICAL IN-SPACE TECHNOLOGY NEEDS**  
**ANTAL K. BEJCZY**  
**JET PROPULSION LABORATORY**

AUTOMATION & ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ROBOTIC SYSTEMS
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# AUTOMATION & ROBOTICS

## THEME ELEMENT #1 : ROBTIC SYSTEMS

1. ACTIVE/PASSIVE COMPLIANCE CONTROL AND PRECISION CONTROL  
IN SMART END EFFECTOR-TOOL-OBJECT INTERACTION
2. DISTURBANCE REJECTION AND STABILIZATION IN ROBOT/PLATFORM  
COUPLING DYNAMICS
3. SENSOR-CORRECTED PLANNED MOTION EXECUTION, INCLUDING  
COLLISION DETECTION AND AVOIDANCE
4. ADAPTIVE CONTROL COORDINATION OF MULTIPLE ARM/END EFFECTOR  
SYSTEMS
5. FAST, HIGH BANDWIDTH AND SMALL-VOLUME CONTROL AND DATA  
PROCESSING ELECTRONICS

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

AUTOMATION & ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	TELEOPERATIONS
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# AUTOMATION & ROBOTICS

## THEME ELEMENT #2 : TELEOPERATIONS

157

1. OPERATOR INTERACTION IN MICRO-G WITH FORCE-REFLECTING CONTROL
2. CONTROL TECHNIQUES FOR COMMUNICATION TIME DELAY CONDITIONS
3. OPERATOR MULTI-MODE MANUAL AND SUPERVISORY CONTROL INTERACTION WITH REMOTE MANIPULATORS
4. INTELLIGENT INFORMATION FUSION DISPLAY SYSTEMS
5. OPERATOR PERCEPTIVE/COMMAND INTERACTION WITH HIGH DEGREE-OF-FREEDOM ARM/END EFFECTOR SYSTEMS

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

AUTOMATION & ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	ARTIFICIAL INTELLIGENCE
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# AUTOMATION & ROBOTICS

## THEME ELEMENT #3 : ARTIFICIAL INTELLIGENCE

1. FAULT DETECTION AND PROCESSING SYSTEMS
2. LARGE INPUT/OUTPUT SENSOR AND SENSOR FUSION SYSTEMS
3. INTEGRATED MODEL AND DATA SENSING INFORMATION SYSTEMS
4. CONTINGENCY MANAGEMENT SYSTEMS
5. PARALLEL, INTEGRATED SYMBOLIC AND NUMERIC DATA PROCESSING AND INTELLIGENT OPERATING SYSTEMS

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

# **SENSORS AND INFORMATION SYSTEMS CRITICAL IN-SPACE TECHNOLOGY NEEDS**

**MARTIN M. SOKOLOSKI  
NASA HEADQUARTERS**

**and**

**JOHN DALTON  
GODDARD SPACE FLIGHT CENTER**

SENSORS & INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	SENSORS
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# SENSORS & INFORMATION SYSTEMS

## THEME ELEMENT #1 : SENSORS

1. SPACE QUALIFIED COOLER AND COOLER SYSTEMS
2. IN-SPACE POINTING AND CONTROL

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

SENSORS & INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	COMMUNICATIONS
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**CRITICAL IN-SPACE TECHNOLOGY NEEDS**

**SENSORS & INFORMATION SYSTEMS**

**THEME ELEMENT #2 : COMMUNICATIONS**

1. IN-SPACE LASER COMMUNICATIONS TECHNOLOGY DEMO.

**NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY**

SENSORS & INFORMATION SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	INFORMATION SYSTEMS
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### CRITICAL IN-SPACE TECHNOLOGY NEEDS

## SENSORS & INFORMATION SYSTEMS

### THEME ELEMENT #3 : INFORMATION SYSTEMS

1. IN-SPACE TESTING/DEMONSTRATION OF HIGHER PERFORMANCE COMPUTERS FOR AUTOMATED OPERATIONS AND ROBOTICS APPLICATIONS
2. IN-SPACE TESTING/DEMONSTRATION OF SPECIAL PURPOSE PROCESSORS (e.g., FROM THE CSTI HIGH RATE DATA SYSTEMS PROGRAM) FOR IMAGE COMPRESSION/PROCESSING FOR SCIENCE EXPERIMENTS AND ROBOTICS APPLICATIONS
3. IN-SPACE TESTING OF HIGH RATE/VOLUME STORAGE DEVICES FOR IMAGE DATA PROCESSING AND COMMUNICATION LINK BUFFERING
4. IN-SPACE TESTING AND CHARACTERIZATION OF RADIATION EFFECTS OF NEXT GENERATION COMMERCIAL AND RADIATION HARDENED DEVICES IN VARIOUS ORBITS FOR GENERAL SPACECRAFT AND INSTRUMENT APPLICATIONS

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY



# **IN-SPACE SYSTEMS CRITICAL IN-SPACE TECHNOLOGY NEEDS**

**JON B. HAUSSLER  
MARSHALL SPACE FLIGHT CENTER**

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MATERIALS PROCESSING
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

### IN-SPACE SYSTEMS

#### THEME ELEMENT #1 : MATERIALS PROCESSING

1. UNDERSTANDING OF MATERIALS BEHAVIOR IN SPACE ENVIRONMENT
2. DEMONSTRATION OF INNOVATIVE IN-SPACE SAMPLE ANALYSIS TECHNIQUES
2. CHARACTERIZATION AND MANAGEMENT OF THE MICRO-G ENVIRONMENT
3. DEMONSTRATION OF IMPROVED SENSING AND IMAGING TECHNIQUES IN EXPERIMENTAL SYSTEMS
4. DEMONSTRATION OF AUTOMATION AND ROBOTICS APPLICATIONS TO MATERIAL PROCESSING SYSTEMS

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	MAINTENANCE, REPAIR, AND FIRE SAFETY
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

### IN-SPACE SYSTEMS

#### THEME ELEMENT #2 : MAINTENANCE, REPAIR, AND FIRE SAFETY

1. DEMONSTRATION AND VALIDATION OF CAPABILITY TO REPAIR  
UNEXPECTED EVENTS
1. INVESTIGATION OF LOW-G IGNITION, FLAMMABILITY/FLAME SPREAD  
AND FLAME CHARACTERISTICS
2. DEMONSTRATION AND VALIDATION OF FLUID REPLENISHMENT  
TECHNIQUES
2. UNDERSTAND BEHAVIOR OF FLAME EXTINGUISHANTS IN SPACE  
ENVIRONMENT
3. DEMONSTRATE ROBOTIC MAINTENANCE AND REPAIR CAPABILITY

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

IN-SPACE SYSTEMS	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	PAYLOAD OPERATIONS
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### CRITICAL IN-SPACE TECHNOLOGY NEEDS

## IN-SPACE SYSTEMS

### THEME ELEMENT #3 : PAYLOAD OPERATIONS

1. DEMONSTRATION AND VALIDATION OF TELESCIENCE TECHNIQUES
2. DEMONSTRATION OF AUTONOMOUS CHECKOUT, PLACEMENT AND SPACE CONSTRUCTION

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

# **HUMANS IN SPACE CRITICAL IN-SPACE TECHNOLOGY NEEDS**

**REMUS BRETOI  
AMES RESEARCH CENTER**

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	EVA / SUIT
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

# HUMANS IN SPACE

## THEME ELEMENT #1 : EVA / SUIT

1. TECHNOLOGY FOR MEASUREMENT OF EVA FORCES, MOMENTS, DYNAMICS, PHYSIOLOGICAL WORKLOAD, THERMAL LOADS, AND MUSCULAR FATIGUE
2. EVALUATION OF COOPERATIVE ROLES BETWEEN EVA AND TELEROBOTS AND FOR IVA AND ROBOTICS
3. SUIT CONTAMINANTS DETECTION, IDENTIFICATION AND REMOVAL

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

### HUMANS IN SPACE

#### THEME ELEMENT #2 : HUMAN PERFORMANCE

1. TECHNOLOGY AND MEASUREMENT OF GRAVITY-RELATED ADAPTATION AND RE-ADAPTATION BEHAVIOR
2. TECHNOLOGY FOR IN-SPACE ANTHROPOMETRIC AND PERFORMANCE MEASUREMENT
3. VARIABLE-GRAVITY FACILITY AND APPLICATION TECHNOLOGY

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	CLOSED LOOP LIFE SUPPORT
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## CRITICAL IN-SPACE TECHNOLOGY NEEDS

### HUMANS IN SPACE

#### THEME ELEMENT #3 : CLOSED-LOOP LIFE SUPPORT

1. IMPROVED PHASE SEPARATION SYSTEMS
2. GRAVITY-INDEPENDENT SENSOR SYSTEMS
3. WASTE-CONVERSION PROCESSES

NOTE: IN PRIORITY ORDER, STARTING WITH 1 AS FIRST PRIORITY



## **APPENDICES**

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APPENDIX A  
FINAL WORKSHOP AGENDA

December 6, 1988

PROGRAM OVERVIEW

- Welcome and Workshop Objectives NASA OAST
- In-Space Technology Experiments in NASA's Strategic Planning NASA OAST
- In-Space Technology Experiments Program NASA OAST
- Space Station Freedom User/Payload Integration and Accommodations NASA OSS

REVIEW OF CURRENT IN-REACH AND OUT-REACH EXPERIMENTS

SPACE STRUCTURES

- In-Space Structural Dynamics Evaluation of a Skewed Scale Truss McDonnell Douglas
- Middeck 0-Gravity Dynamics Experiment (MODE) MIT
- Measurement and Modeling of Joint Damping in Space Structures Utah State University
- Payload Vibration Isolation in Microgravity Environment Texas A&M University
- Generic Pointing Mount Allied/Signal Aerospace
- Space Station Structural Characterization Experiment NASA Langley
- Inflatable Solar Concentrator Experiment L'Garde, Inc.

SPACE ENVIRONMENTAL EFFECTS

- Measurement of Surface Reactions in the Space Environment Globesat, Inc.
- Optical Properties Monitor (OPM) Experiment John M. Cockerham & Associates
- Experimental Investigation of Spacecraft Glow Lockheed
- Return Flux Experiment (REFLEX) NASA Goddard
- Debris Collision Warning Sensors NASA Johnson
- Thin Foil X-Ray Optics Space Environment Contamination Experiment NASA Goddard

POWER SYSTEMS AND THERMAL MANAGEMENT

- Sodium-Sulfur Battery Flight Experiment Ford Aerospace
- Unitized Regenerative Fuel Cell United Technologies
- Thermal Energy Storage Flight Experiments for Solar Dynamics Power Systems NASA Lewis/Boeing Aerospace
- Investigation of Micro-Gravity Effects on Heat Pipe Thermal Performance and Working Fluid Behavior Hughes Aircraft

- A High-Efficiency Thermal Interface (Using Condensation Heat Transfer) Between a Two-Phase Fluid Loop and a Heat Pipe Radiator
- Moving Belt Radiator Dynamics
- Liquid Droplet Radiator

TRW

Arthur D. Little  
Grumman

#### FLUID MANAGEMENT AND PROPULSION SYSTEMS

- Tank Pressure Control Experiment
- Integrated Cryogenic Experiment (ICE) Microsphere Insulation Investigation
- Liquid Motion in a Rotating Tank
- Thermoacoustic Convection Heat Transfer

Boeing Aerospace  
Lockheed

Southwest Research  
Institute  
University of Tennessee

#### AUTOMATION AND ROBOTICS

- Research and Design of Manipulator Flight Testbeds
- Control of Flexible Robot Manipulators in Zero Gravity
- Jitter Suppression for Precision Space Structures
- Passive Damping Augmentation for Space Applications

Martin Marietta  
Utah State University  
McDonnell Douglas  
Old Dominion University

#### SENSORS AND INFORMATION SYSTEMS

- Development of Emulsion Chamber Technology
- Infrared Focal Plane Performance in the South Atlantic Anomaly
- Construction and In-Space Performance Evaluation of High Stability Hydrogen Maser Clocks
- Acceleration Measurement and Management
- Dynamic Spacecraft Attitude Determination with GPS
- Stanford University NASA In-Space Technology Experiment (SUNLITE)

University of Alabama in  
Huntsville  
Lockheed

Smithsonian  
Astrophysical Observ.  
University of Alabama in  
Huntsville  
Mayflower  
Communications  
NASA Langley

#### IN-SPACE SYSTEMS

- Definition of Experiments to Investigate Fire Suppressants in Microgravity
- Risk-Based Fire Safety Experiment Definition
- Plasma Arc Welding in Space
- Extra-Vehicular Activity Welding Experiment
- On-Orbit Electron Beam Welding Experiment
- Laser Welding in Space
- Liquid Encapsulated Float Zone Refining of Gallium Arsenide
- Vapor Crystal Growth Technology

Battelle

UCLA  
University of California  
(Berkeley)  
Rocketdyne  
Martin Marietta  
University of Alabama in  
Huntsville  
McDonnell Douglas

University of Alabama in  
Huntsville

## HUMANS IN SPACE

- Enhancement of In-Space Operations Using Spatial Perception Auditory Referencing (SPAR) University of California (Irvine)
- Definition of a Microbiological Monitor for Application in Space Vehicles University of Alabama in Huntsville
- Design of a Closed Loop Nutrient Solution Delivery System for CELSS (Controlled Ecological Life Support Systems) Application Lockheed
- Impact of Low Gravity on Water Electrolysis Operation Life Systems

December 7, 1988

## THEME REVIEWS (Government, Industry and University Perspectives)

### SPACE STRUCTURES

#### STRUCTURES

- Air Force Wright Aeronautical Lab
- Boeing Aerospace Company
- University of Colorado

#### CONTROL/STRUCTURE INTERACTION

- NASA Langley Research Center
- TRW Space & Technology Group
- Massachusetts Institute of Technology

#### CONTROLS

- NASA Marshall Space Flight Center
- Boeing Aerospace Company
- Purdue University

### SPACE ENVIRONMENTAL EFFECTS

#### ATMOSPHERIC EFFECTS AND CONTAMINATION

- NASA Lewis Research Center
- Martin Marietta Astronautics Group
- University of Alabama in Huntsville

#### MICROMETEROIDS AND DEBRIS

- NASA Johnson Space Center
- McDonnell Douglas Astronautics Company
- University of Colorado

#### CHARGED PARTICLES AND ELECTROMAGNETIC RADIATION EFFECTS

- NASA Langley Research Center
- Jet Propulsion Laboratory
- Jet Propulsion Laboratory

### POWER SYSTEMS AND THERMAL MANAGEMENT

#### DYNAMIC AND NUCLEAR POWER SYSTEMS

- NASA Lewis Research Center
- GE Astro Space Division
- University of New Mexico

#### CONVENTIONAL POWER SYSTEMS

- NASA Lewis Research Center
- GE Astro Space Division
- Auburn University

#### THERMAL MANAGEMENT

- Air Force Wright Aeronautical Lab
- Boeing Aerospace Company
- University of Houston

#### FLUID MANAGEMENT AND PROPULSION SYSTEMS

##### ON-ORBIT FLUID MANAGEMENT

- NASA Lewis Research Center
- General Dynamics Space Systems Division

##### PROPULSION

- NASA Headquarters
- Jet Propulsion Laboratory
- Pennsylvania State University

##### FLUID PHYSICS

- NASA Lewis Research Center
- Southwest Research Institute
- University of Houston

#### AUTOMATION AND ROBOTICS

##### ROBOTIC SYSTEMS

- NASA Langley Research Center
- Martin Marietta Space Systems Company
- University of Texas at Austin

##### TELEOPERATIONS

- NASA Johnson Space Center
- GE Aerospace
- Massachusetts Institute of Technology

##### ARTIFICIAL INTELLIGENCE

- NASA Ames Research Center
- ISX Corporation
- Stanford University

#### SENSORS AND INFORMATION SYSTEMS

##### SENSORS

- NASA Headquarters
- Hughes Aircraft Company
- University of South Florida

##### COMMUNICATIONS

- NASA Headquarters
- Laser Data Technology, Inc.
- Massachusetts Institute of Technology

#### INFORMATION SYSTEMS

- NASA Goddard Space Flight Center
- IBM
- University of Colorado

#### IN-SPACE SYSTEMS

##### MATERIALS PROCESSING

- NASA Headquarters
- Rockwell International Science Center
- University of Arizona

##### MAINTENANCE, REPAIR, AND FIRE SAFETY

- NASA Goddard Space Flight Center
- Wyle Laboratories
- McDonnell Douglas Space Systems Company

##### PAYLOAD OPERATIONS

- NASA Johnson Space Center
- Lockheed Missiles and Space Company
- University of Colorado

#### HUMANS IN SPACE

##### EVA/SUIT

- NASA Ames Research Center
- Lockheed Missiles and Space Company
- Massachusetts Institute of Technology

##### HUMAN PERFORMANCE

- NASA Ames Research Center
- NASA Ames Research Center
- University of Arizona

##### CLOSED LOOP LIFE SUPPORT SYSTEMS

- NASA Ames Research Center
- Boeing Aerospace Company
- University of Colorado

#### BANQUET

- Keynote Address

Harrison H. Schmitt

December 8, 1988

#### THEME SUMMARY DISCUSSIONS

- Space Structures
- Space Environmental Effects
- Power Systems and Thermal Management
- Fluid Management and Propulsion Systems
- Automation and Robotics
- Sensors and Information Systems

NASA Langley  
NASA Johnson  
NASA Goddard  
NASA Lewis  
Jet Propulsion Lab  
NASA Headquarters/  
NASA Goddard

- In-Space Systems
- Humans In Space

NASA Marshall  
NASA Ames

#### EXPERIMENT INTEGRATION PROCESS

- Payload Integration Overview
- Space Shuttle Systems Integration Process
- Complex Autonomous Payload Carriers
- Hitchhiker Project Overview
- Middeck Payload Integration
- KSC Payload Integration Process

NASA Goddard  
NASA Johnson  
NASA Goddard  
NASA Goddard  
NASA Johnson  
NASA Kennedy

December 9, 1988

#### CRITICAL TECHNOLOGY REQUIREMENTS

- Space Structures
- Space Environmental Effects
- Power Systems and Thermal Management
- Fluid Management and Propulsion Systems
- Automation and Robotics
- Sensors and Information Systems
- In-Space Systems
- Humans In Space

NASA Langley  
NASA Johnson  
NASA Goddard  
NASA Lewis  
Jet Propulsion Lab  
NASA Headquarters/  
NASA Goddard  
NASA Marshall  
NASA Ames

#### CONCLUDING REMARKS

NASA OAST



## APPENDIX B - IN-STEP '88 ATTENDEES

Julio Acevedo  
NASA Lewis Research Center

David Akin  
Massachusetts Institute of Technology

Thomas Alberts  
Old Dominion University

Harold Alsberg  
OAO Corporation

Lynn Anderson  
NASA Lewis Research Center

Basil Antar  
University of Tennessee Space Institute

Foster Anthony  
NASA Marshall Space Flight Center

George Apostolakis  
University of California, L. A.

J. Armijo  
General Electric Astro Space

Raymond Askew  
Auburn University Space Power Institute

Frank Austin  
NASA Headquarters

Don Avery  
NASA Langley Research Center

John Aydelott  
NASA Lewis Research Center

Henry Babel  
McDonnell Douglas Astronautics Company

Michael Badgley  
Teledyne Brown Engineering

Richard Baldwin  
NASA Lewis Research Center

Bruce Banks  
NASA Lewis Research Center

C. Bankston  
Jet Propulsion Laboratory

Mark Banyai  
Dynamics Research Corporation

William Baracat  
General Research Corporation

Lyle Bareiss  
Martin Marietta Astronautics

Edward Barocela  
McDonnell Douglas Corporation

Algerd Basiulis  
Hughes Aircraft Company

Sherwin Beck  
NASA Langley Research Center

Albert Behrend  
NASA Johnson Space Center

Antal Bejczy  
Jet Propulsion Laboratory

Michael Bentz  
Boeing Aerospace Company

Jan Bijvoet  
University of Alabama in Huntsville

James Blackmon  
McDonnell Douglas Astronautics Company

J. Blair  
SCI Systems International

Robert Blakely  
Boeing Aerospace Company

Robert Blanks  
University of California, Irvine

Cliff Boehmer  
McDonnell Douglas Corporation

Robert Bosley  
Allied Signal Aerospace Company

Jim Boyd  
Harris Corporation

Richard Boykin  
NASA Langley Research Center

L. Braun  
McDonnell Douglas Corporation

Roger Breckenridge  
NASA Langley Research Center

Patrick Brennan  
OAO Corporation

Remus Bretoi  
NASA Ames Research Center

Jeri Brown  
NASA Johnson Space Center

Wayne Bryant  
NASA Langley Research Center

Edward Bucher  
Massachusetts Institute of Technology Lincoln Labs

John Buckley  
NASA Langley Research Center

David Byers  
NASA Lewis Research Center

James Cake  
NASA Lewis Research Center

Robert Cannon  
Stanford University

Paolo Carosso  
TS Infosystems, Inc.

Manley Carter  
NASA Johnson Space Center

Joseph Casas  
SpaceTec Ventures, Inc.

Michael Cassidy  
Hughes Aircraft Company

Douglas Chalmers  
General Electric Astro Space

Vincent Chan  
Massachusetts Institute of Technology Lincoln Labs

Rebecca Chang  
Ford Aerospace Corporation

Thomas Charlton  
E G & G Idaho, Inc.

C. Chen  
NASA Headquarters

Steve Chinn  
Science & Engineering Associates, Inc.

Edgar Choueiri  
Princeton University

Christopher Chow  
Space Research & Applications Laboratory

Louis Chow  
University of Kentucky

J. Chung  
Washington State University

Lenwood Clark  
NASA Langley Research Center

Bernard Cohlman  
Consultant in Physics & Engineering

Lisa Collier  
Computer Technology Associates, Inc.

Frank Collins  
University of Tennessee Space Institute

David Cooper  
NASA Ames Research Center

Duncan Cox  
Mayflower Communications Company, Inc.

Scott Crocker  
University of Tennessee

Robert Crull  
Teledyne Brown Engineering

Earle Crum  
NASA Johnson Space Center

Ronald Cull NASA Lewis Research Center	Steven Donley The Perkin Elmer Corporation
H. Cullingford NASA Johnson Space Center	Joseph Dubel Sparta Inc.
Robert Culp University of Colorado, Boulder	Joseph Duffy University of Florida
John Dalton NASA Goddard Space Flight Center	A. Dukler University of Houston
Alan Darby Rockwell International	Walter Duval NASA Lewis Research Center
Keith Davis Allied Signal Aerospace Company	Mohamed El-Genk University of New Mexico
Gordon Davison Boeing Aerospace Company	Stephen Ellis NASA Ames Research Center
Dan DeLong Teledyne Brown Engineering	Emily Evans NASA Langley Research Center
Michael Dean Ball Aerospace Systems	Jack Faber University of Colorado, Boulder
Rudolf Decher NASA Marshall Space Flight Center	Edward Falkenhayn NASA Goddard Space Flight Center
Gerard Delaney McDonnell Douglas Corporation	G. Farbman Westinghouse
Robert Dellacamera McDonnell Douglas Space Systems Company	Ken Farnell Teledyne Brown Engineering
Lamont Di Biasi Fairchild Space Company	Ed Fay Sverdrup Technology Inc.
Jacob Dickinson McDonnell Douglas Corporation	Karl Faymon NASA Lewis Research Center
Tony Docal Space Studies Institute	William Ferrell University of Arizona
Franklin Dodge Southwest Research Institute	Dale Fester Martin Marietta Aerospace
Thomas Dollman NASA Marshall Space Flight Center	H. Fisher Lockheed Missiles & Space Co., Inc.
Frank Donovan Jet Propulsion Laboratory	Mike Fitzmaurice NASA Goddard Space Flight Center

**Chris Flanigan**  
SDRC

**George Fleischman**  
Hughes Aircraft Company

**Steven Folkman**  
Utah State University

**Anthony Fontana**  
NASA Langley Research Center

**Thomas Foster**  
Boeing Aerospace Company

**James Fox**  
KMS Fusion, Inc.

**Robert Friedman**  
NASA Lewis Research Center

**Edward Gabris**  
NASA Headquarters

**Joe Galliano**  
Georgia Tech Research Institute

**Mukund Gangal**  
Jet Propulsion Laboratory

**Frank Garcia**  
IBM

**William Gardiner**  
Analytech

**Henry Garrett**  
Jet Propulsion Laboratory

**L. Garrett**  
NASA Langley Research Center

**Richard Gates**  
Boeing Aerospace Company

**Carl Gerhold**  
Texas A&M University

**Elie Gerrels**  
General Electric Aerospace

**Keith Gier**  
Hughes Aircraft Company

**Michael Giesselmann**  
Texas Tech University

**D. Gilluley**  
AAI Corporation

**Rafael Gluck**  
TRW Space & Technology Group

**Linda Godwin**  
NASA Johnson Space Center

**T. Goldsmith**  
NASA Goddard Space Flight Center

**Bruce Goldwater**  
Mechanical Technology, Inc.

**William Grantham**  
NASA Langley Research Center

**John Gregory**  
University of Alabama in Huntsville

**W. Griffiths**  
Foster-Miller, Inc.

**John Haggard**  
NASA Lewis Research Center

**Blake Hannaford**  
Jet Propulsion Laboratory

**Paul Harris**  
Rocketdyne

**Sam Harris**  
Odetics, Inc.

**Leonard Harris**  
NASA Headquarters

**A. Hashemi**  
Lockheed Missiles & Space Co., Inc.

**Leon Hastings**  
NASA Marshall Space Flight Center

**Philip Hattis**  
C. S. Draper Laboratory

**Jonathan Haussler**  
NASA Marshall Space Flight Center

Chris Hawkins  
NASA Johnson Space Center

Robert Hayduk  
NASA Langley Research Center

Russell Haynal  
Grumman Space Station Program Support

E. Heer  
Heer Associates

Barbara Heizer  
Boeing Aerospace Company

Keith Henderson  
NASA Johnson Space Center

Richard Higgins  
U. S. Air Force Space Technology Center

Wayne Hill  
Foster-Miller, Inc.

E. Hinkley  
Hughes Aircraft Company

Irving Hirsch  
Boeing Aerospace Company

Murray Hirschbein  
NASA Headquarters

Jeffrey Hoffman  
NASA Johnson Space Center

Jaak Holemans  
Wyle Laboratories, PSC

Alan Holt  
NASA Headquarters

William Hong  
W. J. Schafer Associates, Inc.

William Hooper  
Martin Marietta

William Howard  
Grumman Space Systems

G. Hubbard  
NASA Ames Research Center

Leigh Hummer  
John M. Cockerham & Associates

J. Hundley  
IBM

David Hunt  
SDRC

Vinod Jalan  
Electrochem, Inc.

Lyle Jenkins  
NASA Johnson Space Center

Gary Johnsen  
Idaho National Engineering Laboratory

Bradley Johnson  
Computer Technology Associates, Inc.

Philip Johnson  
Planning Research Corporation

Robert Johnson  
Martin Marietta Manned Space Systems

James Johnson  
NASA Langley Research Center

Joie Jones  
University of California, Irvine

Peggy Jones  
Fairchild Space Company

Frank Junga  
Lockheed Palo Alto Research Laboratory

Barbara Kanki  
NASA Ames Research Center

William Kaukler  
University of Alabama in Huntsville

Massoud Kaviany  
University of Michigan

James Kelley  
Jet Propulsion Laboratory

Gary Ketner  
Battelle NW Laboratory

Denney Keys  
Ford Aerospace Corporation

Soheil Khajenoori  
University of Central Florida

Taras Kiceniuk  
Jet Propulsion Laboratory

Melvin Kilgore  
University of Alabama in Huntsville

Dennis Killinger  
University of South Florida

Richard Knoll  
NASA Lewis Research Center

Ted Kramer  
Boeing Aerospace Company

Charles Kubokawa  
NASA Ames Research Center

C. Land  
NASA Johnson Space Center

Robert Laurenson  
McDonnell Douglas Astronautics Company

Randy Lavigne  
U. S. Air Force Weapons Laboratory

Lubert Leger  
NASA Johnson Space Center

Harold Leibecki  
NASA Lewis Research Center

Larry Lemke  
NASA Headquarters

Robert Letchworth  
NASA Langley Research Center

Frank Little  
Texas A&M University

Patricia Loegering  
McDonnell Douglas Corporation

Helmut Loesch  
DFVLR

Gene Long  
Odetics, Inc.

James Loos  
Lockheed Missiles & Space Co., Inc.

Leroy Lowery  
NASA Headquarters

Henry Lum  
NASA Ames Research Center

Duane Lundahl  
Rocket Research Company

Charles Lundquist  
University of Alabama in Huntsville

R. MacElroy  
NASA Ames Research Center

Algirdas Maciulaitis  
Grumman Corporation

Tom Mahefkey  
U. S. Air Force Wright Aeronautical Laboratory

M. Mahoney  
Jet Propulsion Laboratory

Carolyn Major  
TRW Space & Technology Group

Joseph Makowski  
Grumman Space Systems

Felix Marcet  
Fairchild Space Company

Neville Marzwell  
Jet Propulsion Laboratory

Craig McCreight  
NASA Ames Research Center

James McElroy  
Hamilton Standard

David McFalls  
Southwest Research Institute

Dennis McGovern  
McDonnell Douglas Astronautics Company

Roy McIntosh  
NASA Goddard Space Flight Center

L. Megill  
Globesat, Inc.

Alfred Meintel  
NASA Langley Research Center

Charles Merkle  
Pennsylvania State University

James Michael  
NASA Langley Research Center

Martin Mikulas  
NASA Langley Research Center

David Miller  
Massachusetts Institute of Technology

Janet Modi  
U. S. Air Force

George Morgenthaler  
University of Colorado, Boulder

Gerald Morrison  
Texas A&M University

Henry Mullaney  
Analytix Electronic Systems

Ralph Muraca  
NASA Langley Research Center

Gerald Murphy  
Jet Propulsion Laboratory

Maurena Nacheff  
Allied Signal Aerospace Company

Timothy Nalette  
Hamilton Standard

David Namkoong  
NASA Lewis Research Center

Clark Neily  
Computer Technology Associates, Inc.

Art Newcomb  
NASA Langley Research Center

Jerry Newsom  
NASA Langley Research Center

G. Nossaman  
IBM

John O'Loughlin  
NASA Johnson Space Center

Susan Olden  
NASA Goddard Space Flight Center

Richard Olson  
Boeing Aerospace Company

David Osterberg  
Honeywell

Henry Osterkamp  
Boeing Aerospace Company

Masood Parang  
University of Tennessee

K. Park  
University of Colorado, Boulder

Jerome Pearson  
U. S. Air Force Wright Aeronautical Laboratory

Shirley Pearson  
McDonnell Douglas Corporation

Stephen Peck  
General Electric Astro Space

James Peebles  
McDonnell Douglas Space Systems Company

Luis Pena  
General Dynamics

Derek Perkins  
KMS Fusion, Inc.

Arthur Perry  
American Space Technology, Inc.

Robert Petre  
NASA Goddard Space Flight Center

Shlomo Pfeiffer  
Grumman Space Systems

Warren Phillips  
Utah State University

Paul Pierson  
General Electric Advanced Technology Laboratories

Larry Pinson  
NASA Langley Research Center

Michael Piszczor  
NASA Headquarters

John Pohner  
TRW Space & Technology Group

William Poley  
NASA Lewis Research Center

David Portnoy  
General Electric Aerospace

Ferolyn Powell  
Life Systems, Inc.

Charles Price  
NASA Johnson Space Center

Clarke Prouty  
NASA Goddard Space Flight Center

John Purchase  
Fairchild Space Company

Jon Pyle  
NASA Headquarters

Francis Quek  
ERIM

Ugo Racheli  
Martin Marietta Astronautics

Charles Raquet  
NASA Lewis Research Center

Marc Rayman  
Jet Propulsion Laboratory

Dean Read  
Lockheed Palo Alto Research Laboratory

Frank Redd  
Utah State University

Rudi Reichert  
Dornier Systems

Ronald Renman  
Grumman Space Systems

Gerald Reuter  
NASA Johnson Space Center

James Reuther  
Battelle NW Laboratory

Richard Rio  
Mechanical Technology, Inc.

Donald Robbins  
NASA Johnson Space Center

William Rock  
NASA Kennedy Space Center

John Rohr  
Jet Propulsion Laboratory

Christopher Rosander  
McDonnell Douglas Corporation

David Rosenberg  
ISX Corporation

Franz Rosenberger  
University of Alabama in Huntsville

Heidi Rosner  
TRW Space & Technology Group

Monte Ross  
Laser Data Technology

Boris Rubinsky  
University of California, Berkeley

Richard Russell  
NASA Langley Research Center

Al Ryan  
Kaman Aerospace Corporation

Jack Salzman  
NASA Lewis Research Center

David Sammons  
University of Arizona



George Saridis RPI	Nancy Sliwa NASA Ames Research Center
Virenda Sarohia Jet Propulsion Laboratory	Olav Smistad Space Industries, Inc.
Chris Schade Orbital Sciences Corporation	John Smith NASA Lewis Research Center
Kenneth Schlichtemeier Electronics Design	Michael Smith Hughes Aircraft Company
Gary Schnittgrund Rocketdyne	Sonya Smith Computer Technology Associates, Inc.
Franz Schubert Life Systems, Inc.	Martin Sokoloski NASA Headquarters
John Schuster General Dynamics	James Spaeth McDonnell Douglas Astronautics Company
Steven Schwartzkopf Lockheed Missiles & Space Co., Inc.	Thomas Sparn University of Colorado, Boulder
Thomas Sheridan Massachusetts Institute of Technology	Larry Spencer NASA Headquarters
Peter Shu NASA Goddard Space Flight Center	John Spofford Martin Marietta Astronautics
David Shuckstes TRW Space & Technology Group	Bernadette Squire NASA Ames Research Center
Edward Silverstein Cubic Defense Systems, Inc.	Lawrence Stark University of California, Berkeley
James Simpson McDonnell Douglas Corporation	John Staudhammer University of Florida
Bob Simpson DARPA	Pamela Stearman Benchmark Technology, Inc.
Robert Skelton Purdue University	John Steffek Lockheed Missiles & Space Co., Inc.
Don Skoumal Boeing Aerospace Company	Bland Stein NASA Langley Research Center
Tom Slavin Boeing Aerospace Company	L. Stephenson U. S. Army Construction Engineering Research Lab
Wayne Slempp NASA Langley Research Center	Chuck Stewart Battelle NW Laboratory

Louis Stodieck  
Bioserve Space Technologies

Donald Strayer  
Jet Propulsion Laboratory

Tom Styczynski  
Lockheed Missiles & Space Co., Inc.

James Sullivan  
Massachusetts Institute of Technology

Theodore Swanson  
NASA Goddard Space Flight Center

Gary Swenson  
Lockheed Palo Alto Research Laboratory

Ralph Taeuber  
NASA Johnson Space Center

W. Teagan  
Arthur D. Little, Inc.

Del Tesar  
University of Texas

Mitch Thomas  
L'Garde, Inc.

Dennis Toney  
McDonnell Douglas Corporation

Yasuhiro Torigoe  
University of California, Irvine

John Tower  
General Electric Advanced Technology Laboratories

Jack Triolo  
NASA Goddard Space Flight Center

Anil Trivedi  
Allied Signal Aerospace Company

William Tumulty  
NASA Goddard Space Flight Center

Richard Tyson  
NASA Headquarters

Eugene Ungar  
NASA Johnson Space Center

Robert Vessot  
Smithsonian Astrophysical Observatory

Faith Vilas  
NASA Johnson Space Center

John Viola  
Rockwell Science Center

Havard Vold  
SDRC

Robert Vondra  
W. J. Schafer Associates, Inc.

Joseph Wachter  
Ford Aerospace Corporation

Benjamin Wah  
National Science Foundation

Robert Walters  
ENTECH, INC.

John Wanhainen  
Sverdrup Technology Inc.

Mike Waterman  
E G & G Idaho, Inc.

J. Watson  
Rocketdyne

William Weber  
Jet Propulsion Laboratory

David Weeks  
NASA Ames Research Center

Neil White  
University of Colorado, Boulder

Donald Wilkes  
John M. Cockerham & Associates

Geoffrey Williams  
L'Garde, Inc.

Kelli Willshire  
NASA Langley Research Center

Larry Witte  
University of Houston

Robert Woolfolk  
SRI International

Gary Workman  
University of Alabama in Huntsville

Paul Wunsch  
Teledyne Brown Engineering

Gary Yale  
U. S. Air Force

Leonard Yarbrough  
University of Alabama in Huntsville

J. Yelverton  
IBM

Wallace Youngblood  
Wyle Laboratories

Robert Zahorchak  
University of Alabama in Huntsville

Dean Zimmerman  
NASA Kennedy Space Center

